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Evaluation of the modified constant wear immersion suit and liners for helicopter aircrew

M.B. Ducharme

Defence R&D Canada – Toronto
Technical Report
DRDC Toronto TR 2005-146
July 2005

Canada

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106-03061/

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Abstract

Many deficiencies have been identified with the current helicopter aircrew constant wear immersion suit (CWS). In collaboration with the CF Directorate of Technical Airworthiness (DTA) and Mustang Survival Inc., DRDC Toronto proposed a series of short-term solutions to resolve some of the most pressing problems. Those solutions include modified fire resistant neck and wrist seals (open seal design) to replace the rubber seals, and a redesigned liner. The objective of this report is to present the results of the evaluation of those solutions in three environmental situations: an aircraft simulated environment trial (Trial #1); a cold water immersion trial (Trial #2); and a flash fire trial (trial #3). Trial #1 was conducted in a climatic chamber at DRDC Toronto maintained at 25°C. During the trial, 7 aircrews from HOTEF were tested during simulated aircrew activities (pilots and backenders) for their physiological heat load, thermal comfort, and sweat transfer into the clothing. Four suit configurations were tested: the current suit and liner (CC); the modified suit (with open neck seal) and Thinsulate® liners (quilted [MQ] and unquilted [MU] liners); and the modified suit and foam liner (MF). The results showed no differences in the heat load between conditions but a better sweat evaporation and transfer for the MU and MQ suits. Trial #2 was conducted in a wave pool at the CORD Group maintained at ~10°C. During the trial, 7 aircrews from HOTEF were tested during a 1-hour immersion in cold water for their skin temperature and heat loss, and the thermal insulation of the suits. Six suit configurations were tested: the MQ suit dry and wet (2 liters of water introduced into the suit); the MF suit dry and wet; and the MW (modified suit with a winter liner similar to the current liner but 3 times thicker) dry and wet. The results showed that the MW suit had the best dry thermal insulation but the MF suit retained best its thermal insulation when wet. The MQ suit had the worst thermal insulation when dry or wet and showed the largest skin heat loss and the lowest skin temperatures. Similar relative insulation results were obtained from the thermal manikin tests (TIM from the CORD Group). Trial #3 was conducted on the Thermo-man® Thermal Protection Evaluation System from DuPont. The MF suit was tested during a standard 4-sec burn test and showed no evidence of skin burn. It is recommended from those trials to adopt the open seals design to improve comfort and sweat transfer through the protective clothing and to select the foam liner because of the better retention of its thermal insulation during water immersion when wet.

Résumé

De nombreuses lacunes ont été décelées sur la combinaison flottante de bord (CFB) que doit porter de façon continue l'équipage d'un hélicoptère. En collaboration avec la Direction - Service technique de la navigabilité aérienne (DSTNA) des FC et de l'entreprise Mustang Survival Inc., RDDC Toronto a proposé une série de solutions à court terme pour régler certains des problèmes les plus pressants. Ces solutions englobent une doublure repensée et des joints modifiés de cou et de poignets résistant au feu (concept de joint ouvert) pour remplacer les joints en caoutchouc. Le présent rapport fait état des résultats de l'évaluation de ces solutions dans trois situations différentes : un essai dans un environnement simulé d'aéronef (essai n° 1), un essai en condition d'immersion dans l'eau froide (essai n° 2) et un essai lors d'un feu à inflammation instantanée (essai n° 3). L'essai n° 1 a été effectué dans une enceinte climatique de RDDC Toronto maintenue à 25 °C. Pendant l'essai, qui consistait à simuler des activités effectuées par le pilote et l'équipage, 7 membres de l'IEEOH ont été *évalués* afin de déterminer la charge thermique physiologique, le confort thermique et le transfert de la sueur aux vêtements. Quatre configurations de combinaisons ont été testées : la combinaison et la doublure actuelles (CC); la combinaison modifiée (avec joint de cou ouvert) et des doublures Thinsulate® (doublures matelassée [MQ] et non matelassée [MU]); et la combinaison modifiée avec doublure en mousse (MF). Les résultats n'ont indiqué aucune différence dans la charge thermique entre les conditions d'essai, mais une meilleure évaporation et un meilleur transfert de la sueur dans le cas des combinaisons MU et MQ. L'essai n° 2 a été effectué dans une piscine à vagues de CORD Group maintenue à ~10 °C. Lors de l'essai qui consistait en une immersion d'une heure dans l'eau froide, 7 membres d'équipage de l'IEEOH ont été évalués afin de vérifier la température cutanée et la perte de chaleur ainsi que l'isolation thermique de la combinaison. Six configurations de combinaisons ont été testées : la combinaison MQ – sèche et humide (2 litres d'eau ayant été versés dans la combinaison); la combinaison MF – sèche et humide et la combinaison MW (combinaison modifiée avec une doublure d'hiver similaire à celle actuellement utilisée mais 3 fois plus épaisse) – sèche et humide. Les résultats ont démontré que la combinaison MW présentait la meilleure isolation thermique à sec, mais que la combinaison MF conservait mieux son isolation thermique lorsque mouillée. La combinaison MQ a affiché les pires résultats – moins bonne isolation thermique, type sec et humide, plus grande perte de chaleur et température cutanée la plus basse. Des résultats semblables pour l'isolation relative ont été obtenus lors des essais réalisés avec le mannequin thermique (TIM de CORD Group). L'essai n° 3 a été mené avec Thermo-man® - le système d'évaluation de la protection contre la chaleur de DuPont. La combinaison MF a été testée lors d'un essai standard d'exposition à un feu de 4 s qui n'a révélé aucune brûlure au corps. À la lumière de ces essais, il est recommandé d'adopter le concept de joint ouvert pour améliorer le confort et le transfert de la sueur aux vêtements de protection et de choisir la doublure en mousse qui offre une meilleure rétention de l'isolation thermique lors de l'immersion dans l'eau lorsqu'elle est mouillée.

Executive summary

Over the years, many deficiencies have been identified with the current helicopter aircrew constant wear immersion suit (CWS). In collaboration with the CF Directorate of Technical Airworthiness (DTA) and Mustang Survival Inc., DRDC Toronto proposed a series of short-term solutions to resolve some of the most pressing problems. Those solutions include modified fire resistant neck and wrist seals (open seal design) to replace the rubber seals, and a redesigned liner to improve comfort in the aircraft and protection during cold water immersion. The objective of this report is to present the results of the evaluation of those solutions in three environmental simulations: an aircraft simulated environment trial (Trial #1); a cold water immersion trial (Trial #2); and a flash fire trial (Trial #3). Trial #1 was conducted in a climatic chamber at DRDC Toronto maintained at 25°C where 7 aircrews from HOTEF were tested during simulated aircrew activities for pilots and backenders. Trial #2 was conducted in a wave pool at the CORD Group maintained at ~10°C where 7 aircrews from HOTEF were tested during a 1-hour immersion in cold water. Trial #3 was conducted on the Thermo-man® Thermal Protection Evaluation System from DuPont. During the Trials #1 and 2, a number of suit configurations were tested: the current suit and liner (CC); the modified suit (with open neck and wrist seals) and Thinsulate® liners (quilted [MQ] and unquilted [MU] liners); the modified suit and foam liner (MF); and a modified suit with a winter liner similar to the current liner but 3 times thicker (MW). During Trial #3, only the suit MF was tested. It is recommended from those trials to adopt the open seals design to improve comfort and sweat transfer through the protective clothing and to select the foam liner (MF) because of the better retention of its thermal insulation during water immersion when wet.

Ducharme, M.B. 2005. Evaluation of the modified constant wear immersion suit and liners for helicopter aircrew. DRDC Toronto TR2005-146 Defence R&D Canada - Toronto.

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Au fil des ans, de nombreuses lacunes ont été décelées sur la combinaison flottante de bord (CFB) que doit porter de façon continue l'équipage d'un hélicoptère. En collaboration avec la Direction - Service technique de la navigabilité aérienne (DSTNA) des FC et de l'entreprise Mustang Survival Inc., RDDC Toronto a proposé une série de solutions à court terme pour régler certains des problèmes les plus pressants. Ces solutions englobent des joints modifiés de cou et de poignets résistant au feu (concept de joint ouvert) pour remplacer les joints en caoutchouc et une doublure repensée afin d'améliorer le confort dans les aéronefs et la protection en situation d'immersion dans l'eau froide. Le présent rapport fait état des résultats de l'évaluation de ces solutions dans trois situations différentes : un essai dans un environnement simulé d'aéronef (essai n° 1), un essai en condition d'immersion dans l'eau froide (essai n° 2) et un essai lors d'un feu à inflammation instantanée (essai n° 3). L'essai n° 1 a été effectué dans une enceinte climatique de RDDC Toronto maintenue à 25 °C où 7 membres de l'IEEOH ont été évalués lorsqu'ils simulaient des activités effectuées par le pilote et l'équipage. L'essai n° 2 a été effectué dans une piscine à vagues de CORD Group , maintenue à ~10 °C, où 7 membres d'équipage de l'IEEOH ont été évalués lors d'une immersion d'une heure en eau froide. L'essai n° 3 a été mené avec Thermo-man® - le système d'évaluation de la protection contre la chaleur de DuPont. Lors des essais n^{os} 1 et 2, un nombre de configurations de combinaisons ont été testées : combinaison et doublure actuelles (CC); combinaison modifiée (avec joints de cou et de poignet ouverts) et doublures Thinsulate® (doublures matelassée [MQ] et non matelassée [MU]); combinaison modifiée avec doublure en mousse (MF), et combinaison modifiée avec une doublure d'hiver similaire à la doublure actuelle, mais 3 fois plus épaisse (MW). Lors de l'essai n°3, seule la combinaison MF a été testée. À la lumière de ces essais, il est recommandé d'adopter le concept de joint ouvert pour améliorer le confort et le transfert de la sueur aux vêtements de protection et de choisir la doublure en mousse (MF) qui offre une meilleure rétention de l'isolation thermique lors de l'immersion dans l'eau lorsqu'elle est mouillée.

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Acknowledgements

The author would like to acknowledge the excellent technical assistance and hard work of Robert Limmer and Debbie Kerrigan-Brown during the trials and the preparation of this report.
The author would like to thank the participation of the aircrews from HOTEF for the trials #1 and 2. Their input and dedication were essential to this evaluation.

Introduction

Over the years, many deficiencies have been identified with the current helicopter aircrew constant wear immersion suit (CWS). These include 1) the fragility and high maintenance of the suits, particularly of the outer Goretex® layer and rubber seals, 2) the presence of uncomfortable and flammable rubber seals, 3) the presence of an uncomfortable liner when damp with sweat, 4) the low thermal protection in water when the liner is wet due to water leakage, and 5) the excessive thermal burden caused by the suit during late spring/early fall operations in the aircraft.

In collaboration with the CF Directorate of Technical Airworthiness (DTA) and Mustang Survival, DRDC Toronto proposed a series of short-term solutions to resolve some of the most pressing problems. Those solutions include 1) replacing the current rubber seals with adjustable fire-resistant seals similar to the ones in use in the MAC 200 immersion suit produced by Mustang Survival; 2) replacing the current liner to improve the sweat distribution and the retention of the thermal insulation when wet.

With the assistance of Mustang Survival, the CWS was modified to accommodate new adjustable fire-resistant neck and wrist seals (Fig. 1), and a new liner (Fig. 2). The new liner incorporated a Coolmax® inner fabric (to improve comfort and sweat distribution over the inner surface of the liner), a non-uniform thermal insulation distribution (to optimize heat retention and heat transfer when and where required), and an insulation material that will retain its thermal properties when wet (See Ciammaichella, 2002 for details).

The objective of the present report is to present the general findings and recommendations that were obtained from a series of three laboratory trials on the modified CWS. The aim of Trial #1 was to test the modified suit for thermal comfort in a simulated aircraft condition during late spring/early fall operation at 25°C, 40% RH. The aim of Trial #2 was to test for the thermal protection of the modified suit during dry (no leakage into the suit) and wet (presence of leakage into the suit) exposures in cold turbulent water. The aim of Trial #3 was to test the modified CWS for its flame resistance properties.

Material and Methods

Trial #1: Aircraft simulation at 25°C

Subjects. Seven subjects (6 males, 1 female) were selected to participate in this trial. The subjects were (mean ± SD) 36.0 ± 9.2 years old, 1.78 ± 0.11 m tall, weighted 84.1 ± 20.1 kg and had a body fat of 19.7 ± 5.9%. All subjects were healthy and had a medical screening before signing for their volunteer consent form. The protocol was approved by the DRDC Human Research Ethics Committee (HREC).

Testing conditions. For this trial, four conditions were tested on each subject. In the first condition, the current suit and current liner were used during the trial (Condition CC). In the second condition, the modified suit (with adjustable neck and wrist seals) and modified liner 1 (Coolmax® inner fabric; un-uniform insulation distribution; unquilted Thinsulate® insulation) were used (MU). In the third condition, the modified suit and modified liner 2 (Coolmax® inner fabric; un-uniform insulation distribution; quilted Thinsulate® insulation) were used (MQ). In the fourth condition, the modified suit and modified liner 3 (Coolmax® inner fabric; un-uniform insulation distribution; perforated foam insulation) were used (MF).

The difference between the different liners was in the type and construction of the insulation material. Both the Thinsulate® and the perforated foam have thermal properties that are better retained even when wet, which is not the case with the batting insulation used in the current liner. It was believed that quilting the Thinsulate® insulation would improve the sweat transfer through the liner for a better thermal comfort in the aircraft.

Clothing. During all the test conditions, the subjects were dressed with the following standard items in addition to their immersion suit: top and bottom long underwear, wool socks, flying summer boots, flying gloves, helmet, uninflated lifevest, and flight pack (only during the flight maneuvers, see below).

Ambient conditions. The four conditions were tested inside a DRDC Toronto climatic chamber maintained at 25°C, and 40% RH. During the simulated flight maneuvers, a 250 W infrared lamp was aimed at each subject to simulate solar load inside the cockpit of the aircraft.

Procedures. Each testing condition lasted 2.3 hrs. It consisted of two phases: a simulated flight maneuver lasting 1.3 hr followed by simulated backender activities lasting 1 hr.

The simulated flight maneuvers consisted of having the subjects sitting on a helicopter seat for 1.3 hr in front of infrared lamps while maintaining a metabolic rate of 1.5 MET. A metabolic rate of 1.5 MET (1.5 times the resting metabolic rate) was defined by Faerevik and Reinertsen (1999) to represent the energy expenditure typically experienced by helicopter pilots during flight operations. The metabolic rate was maintained at 1.5 MET by asking the subjects to operate mockup helicopter foot pedals and stick at a pre-defined rate. The metabolic rate was previously verified using a gas analyzer to calibrate the mockup simulation rate.

The simulated backenders activities consisted of a series of 3 different exercises. Each exercise represented a specific task typically performed by the backenders. Each series of activities was repeated 3 times and separated by a 5 min rest period. Activity 1 consisted of carrying equipment inside the aircraft. Each subject carried a 7 kg weight over a distance of 5 m while stepping over a two-step stairs. This activity was performed until a 1 min elapsed time was over. Activity 2 consisted of pulling a rope with a 7 kg weight equivalent tension from a face down position (duration of the activity: 30 sec). This pulling activity was followed by a cranking activity with both arms using an arm ergometer with a torque of 10 kg from a standing position (duration of the activity: 30 sec). Activity 3 consisted of moving ten 7 kg sand bags into a stokes litter, pulling the stokes litter over a distance of 3 m, and unloading the stokes litter until an elapsed time of 1 min was over.

Termination criteria. An experimental session was terminated if one of the following criteria was achieved: 1) elapsed time of 2.3 hrs; 2) a core temperature of 39.3°C; 3) 95% of the maximum estimated heart rate for three minutes.

Measured parameters. The following parameters were continuously measured on the subjects during the sessions: rectal temperature (as an index of core temperature), skin temperature at 7 locations according to the Dubois weighting system (forehead, abdomen, forearm, hand, thigh, shin, foot), heart rate, and relative humidity at 3 locations inside the clothing between the liner and the shell of the suit (the 3 locations were the chest, back, thigh). The following parameters were measured periodically during the sessions: thermal comfort using the McInnis Thermal Comfort scale, perceived exertion using the Borg Scale, suit comfort, and perceived wetness in the suit (Annex 1). In addition, sweat rate and sweat accumulation in the liner and underwear were also measured at the end of each session by comparing the nude body and clothing weights before and after the sessions. Sweat evaporation was measured by two techniques: sweat evaporation from the skin on the back of the hand was measured once every 20 minutes using a transepidermal water loss recorder (DermaLab, Cortex Technology, Denmark) and total sweat evaporation from the clothing was measured by subtracting the sweat accumulated into the clothing from the total sweat produced by the subjects during the trials.

Statistical analysis. The data were analyzed by repeated measures ANOVA to test for differences over time in the measured variables between the clothing configurations. Significant differences were tested using a Neuman-Keuls post-hoc procedure. Significance was accepted at the $p < 0.05$ level.

Trial #2: Cold water immersion

Subjects. Seven male subjects from HOTEF (CFB Shearwater, NS) with similar characteristics as in Trial #1 were selected to participate in this trial. All subjects were healthy and had a medical screening before signing for their volunteer consent form. The protocol was approved by the DRDC Human Research Ethics Committee (HREC).

Testing conditions. For this trial, six conditions were tested on each subject. All conditions were tested in the CORD Group wave tank (Dartmouth, NS) within a one-week period. Each subject was exposed to the cold water only once a day. The conditions were assigned randomly to each subject, and all tests for the same subject were scheduled at the same time of the day. Two subjects were tested at the same time in the pool and all subjects were tested each day.

Condition 1: modified CWS: foam insulation, dry (Dry MF). In the first condition, the modified CWS was tested with the liner using the perforated foam insulation. All seals were closed before entry to the water to ensure no water leakage into the suit.

Condition 2: modified CWS: foam insulation, wet (Wet MF). The second condition was similar to condition 1, except that 2 liters of water were introduced into the suit through the back of the neck seal before closing all seals for the test. The temperature of the water introduced into the suit was neutral (i.e. 30°C). This condition tested the capacity of the liner to retain its thermal properties when affected by water leakage. The distribution of the water over the body was similar to the distribution normally observed when leakage is present into the CWS.

Condition 3: modified CWS: Thinsulate® insulation, dry (Dry MQ). The third condition was similar to condition 1, except that the liner insulation was Thinsulate®. Previous tests conducted on a thermal manikin showed that the thermal protection provided by the liners using the quilted and the unquilted Thinsulate® were not different during cold water immersion. The quilted Thinsulate® liner was used during Trial 2.

Condition 4: modified CWS: Thinsulate® insulation, wet (Wet MQ). The fourth condition was similar to condition 3, except that 2 liters of water were introduced into the suit similar to condition 2.

Condition 5: modified CWS: winter liner, dry (Dry MW). The fifth condition was similar to condition 1, except that a 2-piece winter liner was used. The insulation material of the 2-piece winter liner was similar to the insulation found in the current liner of the CWS except for its thickness (current liner: 3 mm insulation; winter liner: 10 mm insulation).

Condition 6: modified CWS: winter liner, wet (Wet MW). The last condition was similar to condition 5, except that 2 liters of water were introduced into the suit similar to condition 2.

Clothing. During all the test conditions, the subjects were dressed with the following items in addition to their immersion suit: top and bottom long underwear, wool socks, neoprene gloves, boots and hood, and inflated lifevest.

Ambient conditions. The six conditions were tested at the CORD Group wave tank facilities where the air temperature was maintained at 9.6 ± 0.2 °C and the water temperature at 9.4 ± 0.1 °C. The air and water temperature were similar to facilitate the calculation of the suit thermal insulation. During the water tests, the water was maintained turbulent by generating 30 cm waves (average wave peaks), since it was recently shown by Ducharme and Brooks (1998) that the presence of waves can significantly decrease suit thermal insulation.

Procedures. Upon their arrival at the testing facilities, the subjects were instrumented with skin sensors and dressed with the appropriate immersion suit and clothing. For the wet conditions (conditions 2, 4 and 6), 2 liters of water at 30°C was slowly introduced with a flexible tubing into the back of the suit through the neck seal. Effort was made to distribute the water evenly over the full surface of the back. The weight of the fully dressed subjects was then obtained before moving the subjects to the pool. After positioning the subjects in the pool, flexible positioning cables were attached to one of the subjects' feet to ensure that they would not drift from the test area. The wave generator was then turned on for the duration of the immersion. Each test continued for a maximum of 60 min.

Following the test, the subjects stood beside the pool for a standard period of 2 min to remove the excess of water from the suit before being weighed again. However, the post-immersion weight could not be directly compared to the pre-immersion weight because following the immersion the outside shell of the suit was saturated with water which was not the case during the pre-immersion weighting. To correct for this difference, each test suit was fitted on a subject and was saturated with water during a full water immersion to the neck (with the neck and wrist seals above the water level to eliminate the risk of water leakage into the suit) for a period of 2-min. The weight of the water-saturated suit was then compared (after a standard waiting period of 2

min to remove the excess of water) to the weight of the dry suit before the 2-min immersion and added to the pre-immersion weight obtained before the 60 min tests.

Measured parameters. The following parameters were continuously measured on the subjects during the sessions: skin temperature and heat loss at 12 locations according to a modified Dubois weighting system (forehead, scapula, chest, shoulder, upper arm, lower arm, abdomen, back, front and back thigh, shin, and calf)(Hardy and Dubois, 1938). The suit outer surface temperatures were measured continuously at the same 12 locations to obtain a measure of the suit insulation. The water temperature and air temperature above the test subjects were also measured continuously.

Estimation of survival time. Survival time was estimated for all conditions tested on humans and manikin using the DRDC Cold Exposure Survival Time Prediction Program (Tikuisis , 1999). The survival times were estimated for an average male aircrew of 31 years of age, 79 kg weight and 1.77 m height and exposed to rough sea with 0°C water. The anthropometry of the aircrew represents the average CF aircrew (Stewart, 1985).

Statistical analysis. ANOVA tests were used to analyze differences in skin temperatures, skin heat loss, and suit insulation values between the different conditions. When a significant effect was found ($p < 0.05$), a Mean Contrast Test was used to locate significance between the means using the Greenhouse-Geisser adjusted p-value test.

Trial #3: Flame resistance

Three samples of the modified CWS along with the foam liner and underlying garment were tested for flame resistance according to the "Standard Test Method for Evaluation of Flame Resistance Clothing for Protection against Flash Fire Simulations Using an Instrumented Manikin", ASTM F 1930. ASTM is the American Society for Testing and Materials.

The tests were performed using the Thermo-man® Thermal Protection Evaluation System at the E.I. duPont de Nemours & Co. (Inc.) in Richmond, VA. Three identical tests were conducted on three samples of the same clothing configuration. The clothing consisted of long underwear, socks, new immersion suit liner (non-uniform perforated foam insulation, inner Coolmax® fabric, Nomex® shell), modified CWS (flame resistant adjustable neck and wrist seals, Nomex® shell, Goretex® layer), anti-G garment, survival vest, flight helmet, flight gloves and liners and leather flight boots.

The test specifications were as follows:

exposure time to flame: 4 sec
exposure heat flux: 2 cal/cm^2/sec
scan interval of the skin sensors: 0.5 sec
acquisition time: 60 sec
clothing saturation condition before test: 31°C, 53% RH, 5km/h wind., 3 hours

An additional test was conducted on a similar clothing configuration where the only change was the exposure time to flame that was increased to 10 sec.

Following the burn tests, the sleeves from two suits were carefully cut and tested for water leakage at DRDC Toronto. The sleeves were mounted on a stand and filled with a known mass of dry absorbent material (see Figure 3). The sleeves were then immersed in water for a period of 2 and 5 minutes. Following the immersion, the absorbent material was weighted again to define the amount of water leakage into the sleeve.

Results

Trial #1: Aircraft simulation at 25°C

During the trial, a number of subjects terminated their exposure before the completion of the full protocol (2.3 hours) mainly because of an elevated heart rate (>95% maximum heart rate for over 3 minutes).

Mean skin temperature. Figure 4 presents the mean skin temperature for the 7 subjects over the 2.3-hours simulation. No difference was observed between the conditions during the first 1.3 hour of simulated flight maneuvers (resting phase). Over the next hour of simulated backender activities (exercising phase), the mean skin temperature was not different between conditions, although the values from time 110 min appears to be lower for the MU condition. No statistical analysis could be performed beyond 105 min because of the low number of subjects.

Mean rectal temperature. Figure 5 presents the mean rectal temperature for the 7 subjects over the 2.3 hours simulation. During the resting phase, the mean rectal temperature for the CC condition was lower compared to the MU condition and lower than MQ condition for less than half of the resting phase. The mean rectal temperature for the CC condition was not different compared to MF condition apart from a few minutes in the first half of the resting phase. The mean rectal temperature was not different between the MU and MQ conditions apart from a few minutes late in the run. The mean rectal temperature was higher in the MU and MQ conditions compared to the MF condition for the entire resting phase.

During the exercising phase, the mean rectal temperature for the CC condition was lower than the MU condition and lower than the MQ condition for more than half the phase. The mean rectal temperature was not different between the CC and MF conditions and between the MU and MQ conditions. Higher mean values were observed for the MU condition compared to MF condition, and for the MQ condition compared to the MF condition.

All differences observed in the mean rectal temperatures were attributed to an initial difference before the start of the trials, and not to the simulation or the different conditions tested.

Mean sweat evaporation rate from the clothing. Figure 7 presents the mean sweat evaporation rates for the 7 subjects over the entire simulation for all conditions. The mean evaporation rates were significantly higher for the MU and MQ conditions as compared to CC and MF conditions. The rates for MU and MQ were not different, and similarly the rates for CC and MF were not different.

Mean sweat accumulation inside the clothing. Figure 13 presents the mean sweat accumulation inside the liner and underwear for the 7 subjects over the entire simulation for all conditions. The mean sweat accumulation inside the liner was significantly lower for the CC condition compared to the other conditions and no difference was observed between MU, MQ and MF. The mean sweat accumulation inside the underwear was significantly higher for the CC condition compared to the other conditions and no difference was observed between MU, MQ and MF.

Mean vapour pressure inside the clothing. Figure 14 presents the mean vapour pressure inside the clothing for the 7 subjects over the entire simulation for all conditions. No difference was observed between conditions for the resting and exercising phases for both the chest and front thigh locations. For the lower back position, no difference was observed between conditions for the resting phase. During the exercise phase, no difference was observed between the CC, MU and MQ conditions. The mean vapour pressure was larger for the MF condition compared to the MU (entire 1 hour), MQ (last 54 min) and CC (several minutes intermittently over the hour) conditions.

All other measured parameters. Figures 6, and 8 to 12 present the mean results for the heart rate, sweat rate, rate of perceived exertion, thermal comfort, suit comfort, and suit wetness. No difference was observed between conditions for all those parameters for both the resting and exercising phases.

Subjects comments on the suits. Table 1 presents the comments provided by the subjects regarding the comfort of the modified seals compared to the rubber seals.

Trial #2: Cold water immersion

Mean skin temperature. Figure 15 presents the mean skin temperature for the 7 subjects over the 60 min water immersions for all conditions tested. The mean skin temperature was significantly higher for all dry conditions when compared to the wet conditions. The highest mean skin temperatures were observed for the conditions using the winter liner (Dry MW and Wet MW) as compared to the other two liners. The coldest mean skin temperatures were observed for the conditions using the Thinsulate® liner (Dry MQ and Wet MQ).

Mean skin heat loss. Figure 16 presents the mean skin heat loss for the 7 subjects over the 60 min immersions for all conditions tested. The mean skin heat loss was significantly higher for all wet conditions when compared to the dry conditions. The lowest mean skin heat losses were observed for the conditions using the winter liner (Dry MW and Wet MW) as compared to the other two liners. The highest mean skin heat losses were observed for the conditions using the thinsulate® liner (Dry MQ and Wet MQ).

Mean suit insulation from the human tests. Figure 17 presents the mean suit insulation for the 7 subjects over the 60 min immersions for all conditions tested. The mean suit insulation was significantly higher for all dry conditions when compared to the wet conditions. The highest mean suit insulations were observed for the conditions using the winter liner (Dry MW and Wet MW) as compared to the other two liners. The lowest mean suit insulations were observed for the conditions using the Thinsulate® liner (Dry MQ and Wet MQ).

Water leakage into the suits. In a perfect dry suit system, the volume of water into the suit at the end of the tests should have been 0 L for the dry tests and 2 L for the wet tests. It was measured that at the end of the 60 min immersion, an average of 0.345 ± 0.137 L of additional water was present into the suit for the dry tests and 2.278 ± 0.159 L for the wet tests. The additional water leakage during the 60 min tests was significantly greater for the dry tests by an average of 67 mL.

Suit insulation from the manikin tests. Figure 18 presents the thermal resistance of the modified CWS obtained during the manikin tests for the same conditions as the ones tested on humans. In addition, Figure 18 presents the thermal resistance of the current un-modified CWS for a dry (no water leakage) and wet (2 L water leakage) condition. The latest results obtained for the current CWS were obtained from a test performed at the CORD Group in 2000 for similar ambient conditions (unpublished data).

Estimated survival times for the human and manikin tests. Table 2 presents the estimated survival times for the different conditions tested in the present study. In addition, the survival times are provided for the non-modified CWS for the manikin and the human tests in the dry and wet conditions, with the exception of the human tests under wet conditions were no data are available. The thermal resistance data for the non-modified CWS were obtained from different studies conducted at the CORD Group between 1996 and 2000 (unpublished data) using similar testing conditions as in the present study. It is observed from the manikin tests that in the presence of water leakage, the survival times decrease on average to just over 5 hours for the current CWS and for the modified CWS with the winter and Thinsulate® liners. When water leakage is present in the modified CWS with the foam liner, the survival time is decreased to 7.6 hours.

From the human tests, the shortest survival time was observed for the modified CWS with the Thinsulate® liner (11 hours) under wet condition. The modified CWS with the winter liner provides the best insulation under water leakage condition with about 17 hours of survival time. The modified CWS with foam liner provides the best retention of insulation under water leakage with 15.5 hours of survival time. Unfortunately, no data are available for the effect of water leakage into the current CWS when measured on humans.

Trial #3: Flame resistance

The information provided by the manikin was the predicted % surface area with 2nd and 3rd degree burn injury based on the surface temperature of the manikin obtained during the burn tests. No information was reported for the hands, feet and the head (corresponding to 7% body surface area). The three 4-sec tests showed consistent results: no predicted 2nd or 3rd degree burn injury was reported on the body. Following the 4-sec burn tests, there was between 2.8 and 3 sec general surface afterflame, lingering at the sleeves, feet and various items on the lifevest and cuff Velcro®. Annex 2 presents the results provided by DuPont for the three 4-sec burn tests on the modified CWS. Note that the 3rd degree burn injury on 7% body surface area mentioned in the DuPont report is for the unprotected areas of the body.

The single 10-sec burn test predicted a 2nd / 3rd degree burn injury on 1% surface area and observed on the shoulder of the manikin. Following the 10-sec burn test, vigorous afterflame was observed all over the garment, with lingering flame at the meltable hardware. Annex 3 presents the results provided by DuPont for the three 10-sec burn tests on the modified CWS. Note that the 3rd degree burn injury on 7% body surface area mentioned in the DuPont report is for the unprotected areas of the body.

Table 3 presents the water leakage into the sleeves of the immersion suit following a 4-sec burn test. It shows that on average, 281g of water were entering the sleeve per minute of water immersion and that all the sleeves tested were leaking. The range in the rate of water ingress was substantial (40 to 530 g/min) and was related to the extent of the burn damage to the Goretex® layer of the sleeve.

Discussion

Trial #1: Aircraft simulation at 25°C

The results from this trial show that the different immersion suit conditions tested made no difference on the physiological parameters measured from the aircrew: all aircrews were heat stressed and many of them had to withdraw before the end of the trial mainly because of an elevated heart rate above their 95% maximal value. This precluded statistical analysis beyond 105 min (only 15 min into the exercising phase) because of the attrition of the subjects during the exercising phase. The compounded effect of the physical activities and the heat stress was responsible for the elevated heart rate during the simulations. These results tend to demonstrate that the conditions used in the simulations might have been too harsh for the aircrew. Indeed, no prolonged rest periods were provided during the 1-hour exercising phase. Despite efforts to simulate the backender's activities during flight operations, the level of workload was probably too elevated for the ambient and clothing conditions. Future experiments simulating backender's activities should incorporate longer rest periods to simulate more closely the level of physical workload experienced by aircrews during flight operations.

Despite the absence of physiological differences, the type of protective clothing made a difference on the rates of sweat evaporation and sweat accumulation into the underwear and liners. It was observed that both modified suits with Thinsulate® liners provided a larger rate of sweat evaporation from the clothing to the environment when compared to the modified suit with foam liner and the current suit. Furthermore, the current suit accumulated significantly more sweat closer to the skin into the underwear, as compared to the other suits tested. The other suits (MU, MQ and MF) accumulated more sweat away from the skin into the liner layer. Those factors would impact on the comfort of the aircrew when they are sweating during flight operations and would contribute to making the current suit less comfortable than the modified suits with Thinsulate® or foam liners. One factor that likely contributed to the sweat movement away from the skin and to the environment is the open neck seal of the modified suits.

Based on those results, it would be advantageous probably to select a modified suit and a Thinsulate® liner to optimize the transfer of sweat away from the skin and towards the environment. Further tests using longer rest periods and possibly lower work load would be required to test the effect of using a modified immersion suit with a Thinsulate® liner on the thermal load of aircrews.

Based on the subjective comments from the aircrew subjects, they appreciated the open neck seal design and found it more comfortable to wear. This preference did not

reflect however on the thermal comfort rating probably because of the elevated discomfort associated with the high work load and associated heat load.

Trial #2: Cold water immersion

Manikin tests. Manikin tests conducted on the current immersion suit showed that the suit insulation is seriously affected by water leakage (53 % decrease in insulation) as compared to the modified suits with Thinsulate® liner (44% decrease) or with foam liner (34% decrease). Since the liner used in the MW condition is made of the same insulation material as the current liner, it is not surprising to see a similar decrease in thermal insulation during water leakage tests for both suits (53% decrease for CC; 56% decrease for MW). This finding was the basis for testing other insulative materials for the liner such as Thinsulate® (MQ) and closed perforated foam (MF). Based on the data from Table 2, it was observed from manikin results that indeed the relative insulation of the MQ and MF suit is better maintained during the wet condition as compared to the CC or MW conditions, and the absolute insulation is the highest for the MF suit during the wet condition. The better thermal insulation of the MF suit as obtained by the manikin test during wet condition will increase the survival time of aircrew exposed to cold water by 2 hours when compared to all other suits.

The modified immersion suit with the winter liner (MW). The winter liner tested during the Trial #2 was the thickest of all the liners tested. For this reason, the larger thermal resistance was obtained during the dry tests during the MW condition for both the manikin and human tests. Although the insulation of the MW condition was not tested in air, it is very likely that this condition would provide the highest thermal insulation of all suits conditions and therefore could impose the highest heat stress during flight operations outside the winter season (unfortunately, the MW condition was not tested in the Trial #1). So if the MW is selected, it should be limited to winter season to avoid heat stress and similar level of discomfort observed in the current suit when sweating is present. Furthermore, because of the liner insulation used with the MW suit, it is likely that the insulation will be severely affected when wet (see results from Table 2) and may not be better than the other suit conditions despite its thickness.

During the immersion tests using the MW suit, it was observed that the larger subjects had great difficulty in donning the suit because of the thickness of the winter liner. The shell of the suit needed to be larger to accommodate the winter liner, particularly at the sleeves. The design of the suit may need to be modified if the winter liner is selected.

The modified immersion suit with the quilted Thinsulate® liner (MQ). The tests performed on the aircrew showed that the MQ condition provided the lowest mean skin temperature and the highest mean skin heat loss of all conditions for both wet and

dry conditions. In addition, the thermal insulation provided by the MQ suit was significantly lower than the other conditions which translates into the lowest survival time for both the wet and dry conditions (see Table 2).

The modified immersion suit with the foam liner (MF). The MF condition with the foam liner is the suit that retained best its thermal insulation during the wet tests for both the manikin and human trials. The thermal insulation during the wet tests was the highest for the MF condition when tested on the manikin and just slightly lower than the MW condition when tested on humans. The better insulation of the MF suit when wet is estimated to improve the survival time by over 5 hours based on human data and by 2.5 hours based on the manikin data when compared to the MQ condition. When compared to the CC condition, the manikin data show that MF during the wet tests could increase the survival time by about 2 hours. Unfortunately, no data are available for the humans during wet tests.

Estimated survival times. The estimated survival times are significantly longer for all dry conditions when compared to the wet conditions for all the suits tested. Although the estimated survival times are different between the manikin and human tests, it is nevertheless safe to conclude that the estimated survival times are sufficient for the dry conditions independent of the suit conditions since the lowest survival time estimated is close to 11 hours (dry manikin test for MQ condition; see Table 2). Therefore, the selection of the suit should be based on the wet tests since this is where the shortest estimated survival times was observed. Based of the tests on the manikin and humans, the suit condition that retained best its thermal insulation when wet was the MF condition (see discussion above).

Differences in the measured thermal insulation of the immersion suits obtained between the manikin and the human tests have been reported previously (Ducharme et al, 1999). Many reasons have been raised to explain the differences in the results: different interaction between the test subjects (manikin or human) with the wave motion (different convective heat transfer), different skin temperature distribution between the manikin and the humans; different methods of calculations, different fit of the clothing, improper calibration of the manikin, etc. Despite some answers from the early studies, further investigations are needed to fully understand the differences between manikin and human tests.

Trial #3: Flame resistance

The results obtained during these tests clearly showed that the modified immersion suit and liner meet the safety requirements for a 4-sec flame resistance test with no burn observed. Even a more severe 10-sec test showed minimum percentage of burn.

Of particular interest is the fact that following the burn test, the waterproof GoreTex® membrane of the suit is not functional and will likely leak badly during an immersion in water. The consequence of this is that if an aircrew is lucky enough to survive an ejection and a burn threat, he/she may not survive a prolonged immersion in cold water because of massive leakage of water into his/her suit. Such a hypothesis would need to be tested to evaluate the extent of the problem.

Recommendations

1. From Trial #1, it is recommended that the open seals design be adopted because it provides greater comfort (based on subjective comments) and will promote the transfer of sweat from the skin to the environment.

2. From Trial #1, it is recommended the modified suit with the Thinsulate® liner (MQ or MU) be adopted because it provides a greater rate of sweat evaporation from the suit and a greater transfer of sweat from the skin to the outer layers of the suit. Despite those advantages, however, no differences were observed for the heat load and thermal comfort between conditions. Further tests with milder workload conditions would be required to prove that the modified suit with a Thinsulate® liner would provide a physiological advantage over the other conditions.

3. From Trial #2, it is recommended that the modified suit with the foam liner (MF) be adopted because the liner retains best its thermal insulation in the presence of water leakage when compared to the other liners. This condition provided the best (from manikin tests) or acceptable (from human tests) estimated survival time during exposure to cold water.

4. From Trial #3, it was found that the modified suit with the foam liner provides adequate protection against fire treat, but inadequate protection against cold water immersion following exposure to a 4-sec flash fire because of the damaged GoreTex® layer of the suit.

Table 1. Comments from the subjects during trial #1 for all conditions tested.

SUIT	SUBJECT	COMMENTS
CC	1	No comments
	2	00:58:20- warm everthing else is fine 01:57:26- same shoulder tightness as yesterday cooler than last MU
	3	Dressing room hot – subject warmer and sweating more before entering chamber.
	4	00:19:38- much warmer in chest area, normal day in the suit 01:15:18- back a bit sweaty 01:35:30- warmer all over, not uncomfortable 01:55:26- sweaty all over, very warm mostly chest and upper arm 02:07:49- sweaty and hot
	5	00:16:45 **neck seal more constrictive than other suit**. 1:40:00 feels much warmer than yesterday (MU), chest feels better. 1:57:50 Seals in heat/sweat more than others. Can feel the heat more especially down the thighs. 2:17:00 more sweat in face.
	6	00:15:00- warm 00:35:00- comfortably warm 00:58:27- getting warmer, but still comfortable 01:15:00- same as last run, getting warm, not bad 0:1:35:57- increased work-load, increased sweat. Thighs and up had even distribution of heat 02:00.00- sweating profusely, lights not even close to simulating heat load from the sun 02:15:00- nearing max heat, sweating continuously
	7	Subject said that run 2(MU) and this run were the worst of the 4 runs and that this was the very worst.
MU	1	Feels no difference in suits so far (MQ, MF). Reports that activities are now "learned" well.
	2	00:16:50 comfortable, warm no pinch points 00:37:06- same, warm, not unbearable 01:16:37- warm, same 01:37:25- during work above the head, caused resistance top of the shoulders; warm, feels fine 01:56:26- warm +, shoulder tightness, no irritation or rubbing after finish- no change
	3	At 100 min hotter than previous days (MF, MQ)
	4	No comments
	5	00:57:37- liner seems cooler than MQ
	6	At 60 min. he feels he is sweating less. Feels that there is an even heat. He has the same energy level as yesterday (MQ). He could continue if needed by the end.
	7	Felt hotter in this suit than previous (MF)

Table 1 Continued.

Suit	Subject	Comments
MQ	1	Helmet uncomfortable.
	2	No comment
	3	00:39:00- chest feels damper than the body 01:16:12- **neck seal is very comfortable**, left shoulder same as yesterday (i.e.MF), finished early for HR, stated he would have gone on longer
	4	47:30 Slightly warmer 1:41:10 Chest feels cooler. Expected to be wetter after exercise 1:58:55 **Neck seal great**, feel very damp, feels hotter from the waist down, less facial sweat 2:17 Chest relatively cool compared to rest of body
	5	00:18:11- not too bad 01:16:19- none 01:36:34- doesn't feel different from other liner, **neck seal nicer**
	6	At 100 min. not as hot as yesterday (MF). At end still has energy whereas after his first run (CC) had no energy.
	7	Body felt tingly.
MF	1	Learning and making movements more efficient with time.
	2	No comment
	3	00:15:00- padding in back is fairly comfortable 00:56:30- back quite comfortable, left shoulder starting to get sore (near belt) 01:16:10- liner back the same, **neck seal is quite comfortable**, no noticeable hot spots 01:36:50- even thermal distribution, trial representative of high workload
	4	00:56:50- **feel the neck breathing, feels good** 01:55:51- chest less warm than CC, too much fabric in seat of liner, could be the new shell verses old shell?
	5	No comments
	6	00:15:30- warm, comfortable 00:38:16- feels warmer and sweaty more in the back area 00:01:15- sweating pretty good, liner chest is drier, neck seal is fine , but doesn't mind the current one 01:36:00- hotter than last liner on the back, legs and arms.(last liner was CC) Sweating profusely. No difference in neck. Finish time- feels better with trial physically, no difference in the suit.
	7	Suit felt bulky – difficult to move in it.

Table 2 . Estimated survival time (in hours) for the modified and current Constant Wear Immersion Suit (CWS) using the DRDC Cold Exposure Survival Time prediction program. The survival times are for a male aircrew of 31 years of age, 79 Kg weight and 1.77 m height exposed to rough sea with 0°C water.

Conditions	Leakage	Manikin tests		Human tests	
		Thermal resistance (Clo)	Survival time (Hours)	Thermal resistance (Clo)	Survival time (Hours)
CC	Dry	0.80	15.7	1.31	>36
	Wet	0.38	5.4	-	-
MW	Dry	0.91	19.9	1.40	>36
	Wet	0.40	5.8	0.85	17.4
MF	Dry	0.77	14.7	1.10	27.9
	Wet	0.51	7.6	0.80	15.5
MQ	Dry	0.64	10.7	0.95	21.6
	Wet	0.36	5.1	0.65	11.1

Table 3 . Water ingress into the sleeve of the modified constant wear immersion suit following a 4-sec burn test. The water immersion test lasted 2 to 5 min.

SLEEVE #	IMMERSION TIME (MIN)	WATER INGRESS (G)	RATE OF INGRESS (G/MIN)	ESTIMATED AREA UNDER WATER (CM^2)
1	5	2070.4	414.08	1500
2	2	80.1	40.05	1500
3	2	1060.5	530.25	1500
4	2	276.6	138.3	1500

Proposed
Adjustable seal

Current rubber
seal

Figure 1. Modification 1: Neck seal. The current rubber seal of the CWS is replaced by an adjustable fire retardant neck seal.

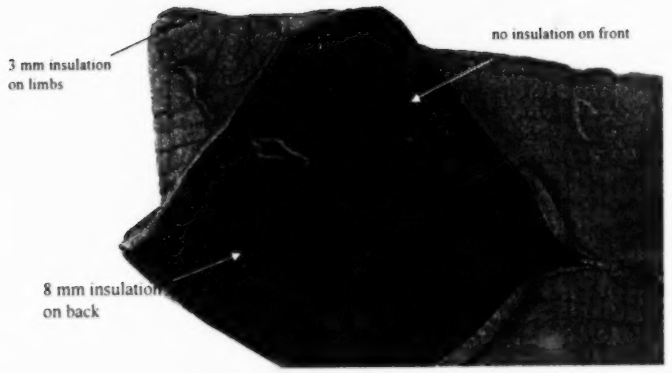


Figure 2. Modification 2: Liner. The current liner is replaced by a non-uniform liner with a Coolmax® inner fabric and a Nomex® outer fabric.

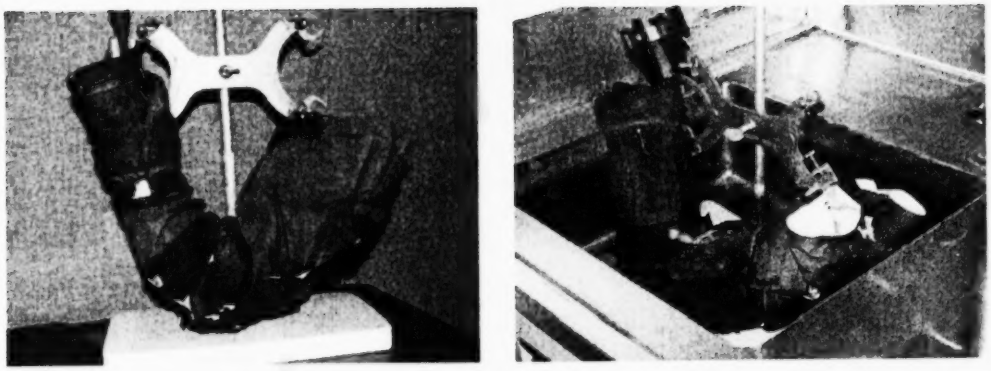


Figure 3. Experimental set-up to test the sleeves for water leakage following the 4-sec burn tests.

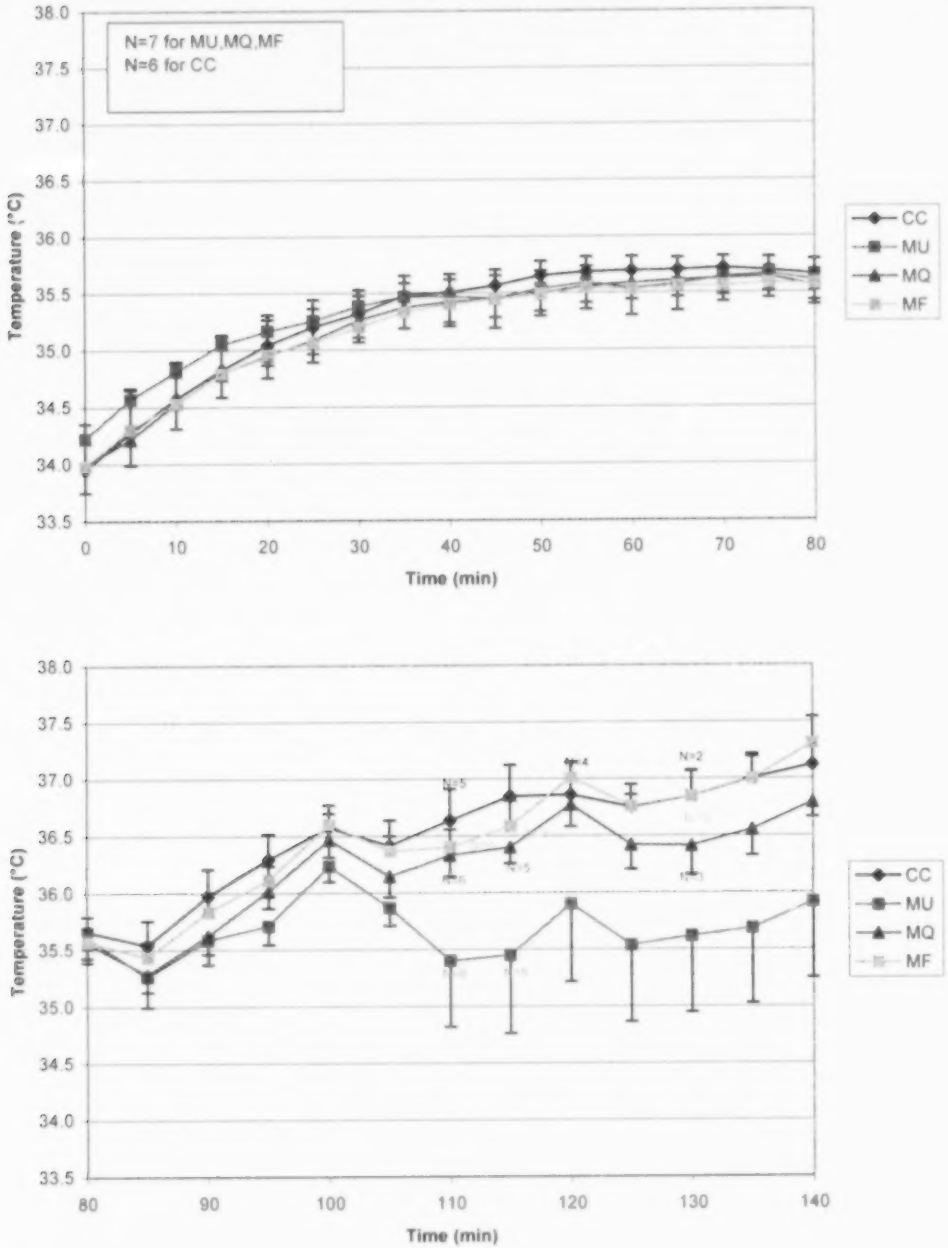


Figure 4. Weighted mean skin temperatures for the 80 min. resting phase (top). Weighted mean skin temperatures for the 60 min. exercising phase (bottom). CC: current suit and liner; MU: modified suit with unquilted Thinsulate®; MQ: modified suit with quilted Thinsulate®; MF: modified suit with foam.

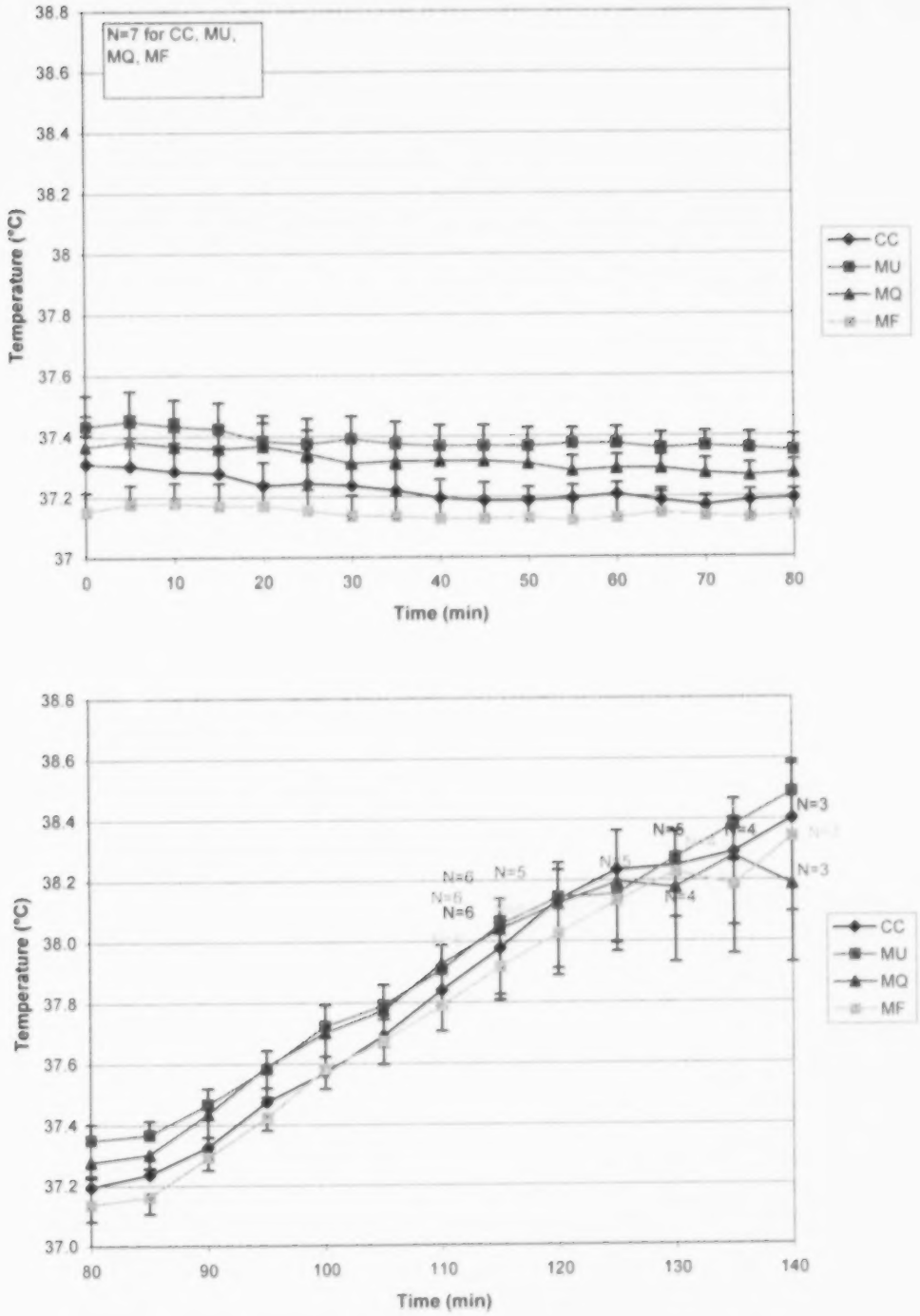


Figure 5. Mean rectal temperatures for the 80 min. resting phase (top). Mean rectal temperatures for the 60 min. exercising phase (bottom). CC: current suit and liner; MU: modified suit with unquilted Thinsulate®; MQ: modified suit with quilted Thinsulate®; MF: modified suit with foam.

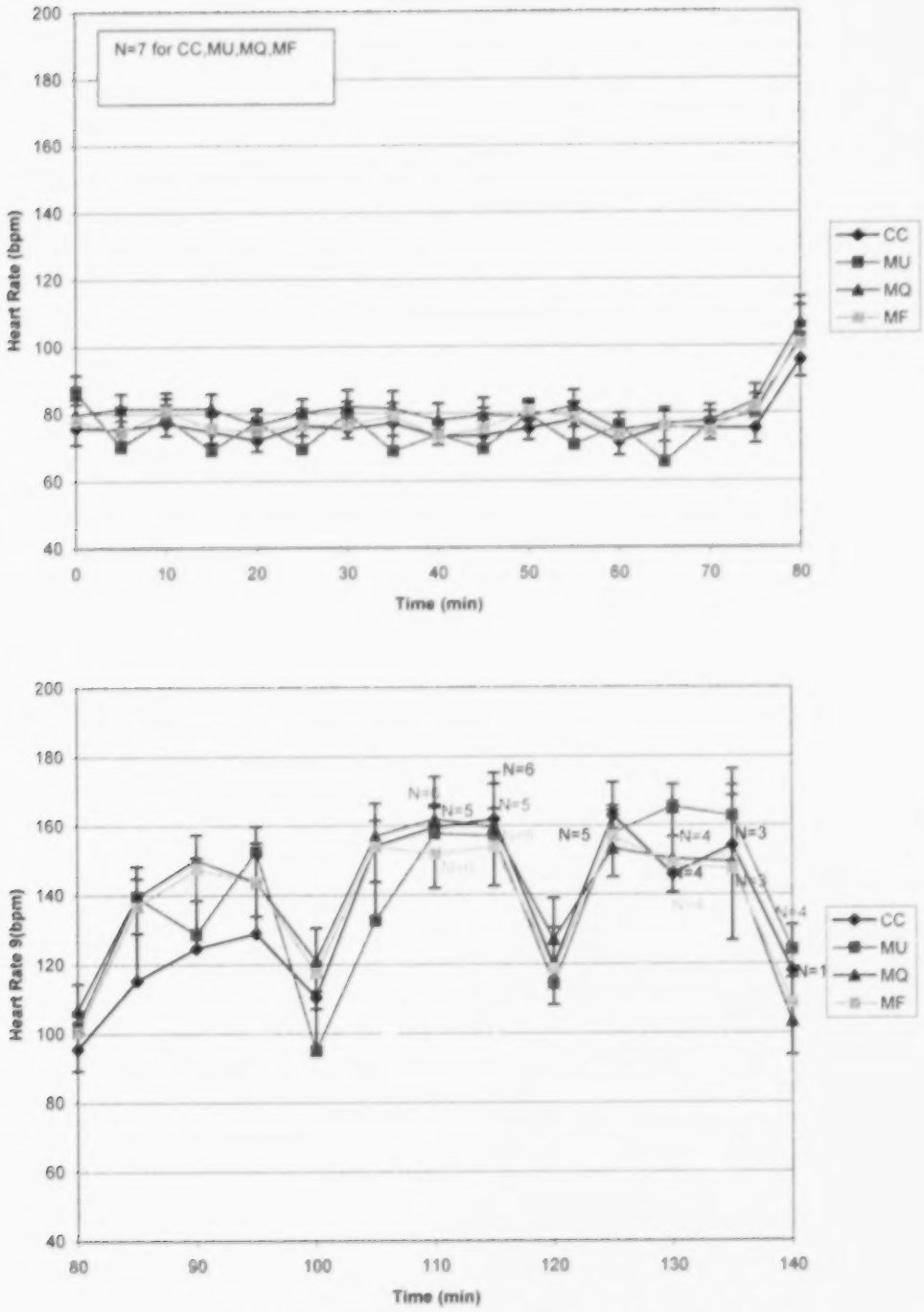


Figure 6. Mean heart rates for the 80 min. resting phase (top). Mean heart rates for the 60 min. exercising phase (bottom). CC: current suit and liner; MU: modified suit with unquilted Thinsulate®; MQ: modified suit with quilted Thinsulate®; MF: modified suit with foam.

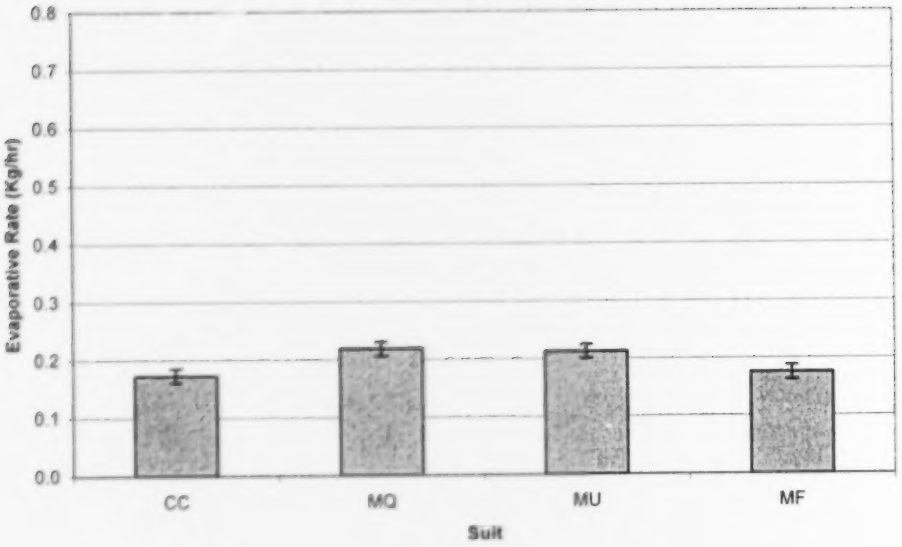


Figure 7. Mean evaporation rate for the 7 subjects during the 2.3 hour trials for the conditions tested. CC: current suit and liner; MU: modified suit with unquilted Thinsulate®; MQ: modified suit with quilted Thinsulate®; MF: modified suit with foam.

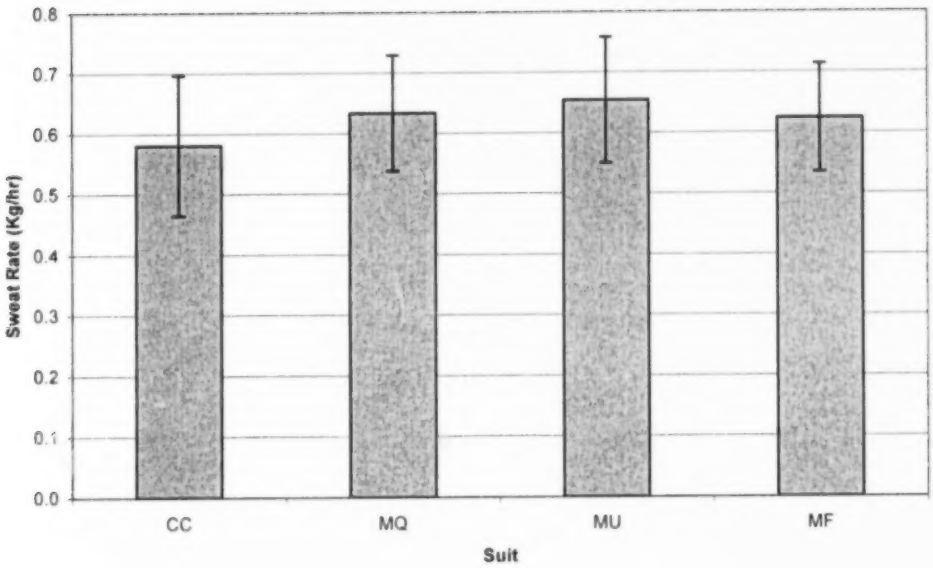


Figure 8. Mean sweat rate for the 7 subjects during the 2.3 hour trials for the conditions tested. CC: current suit and liner; MU: modified suit with unquilted Thinsulate®; MQ: modified suit with quilted Thinsulate®; MF: modified suit with foam.

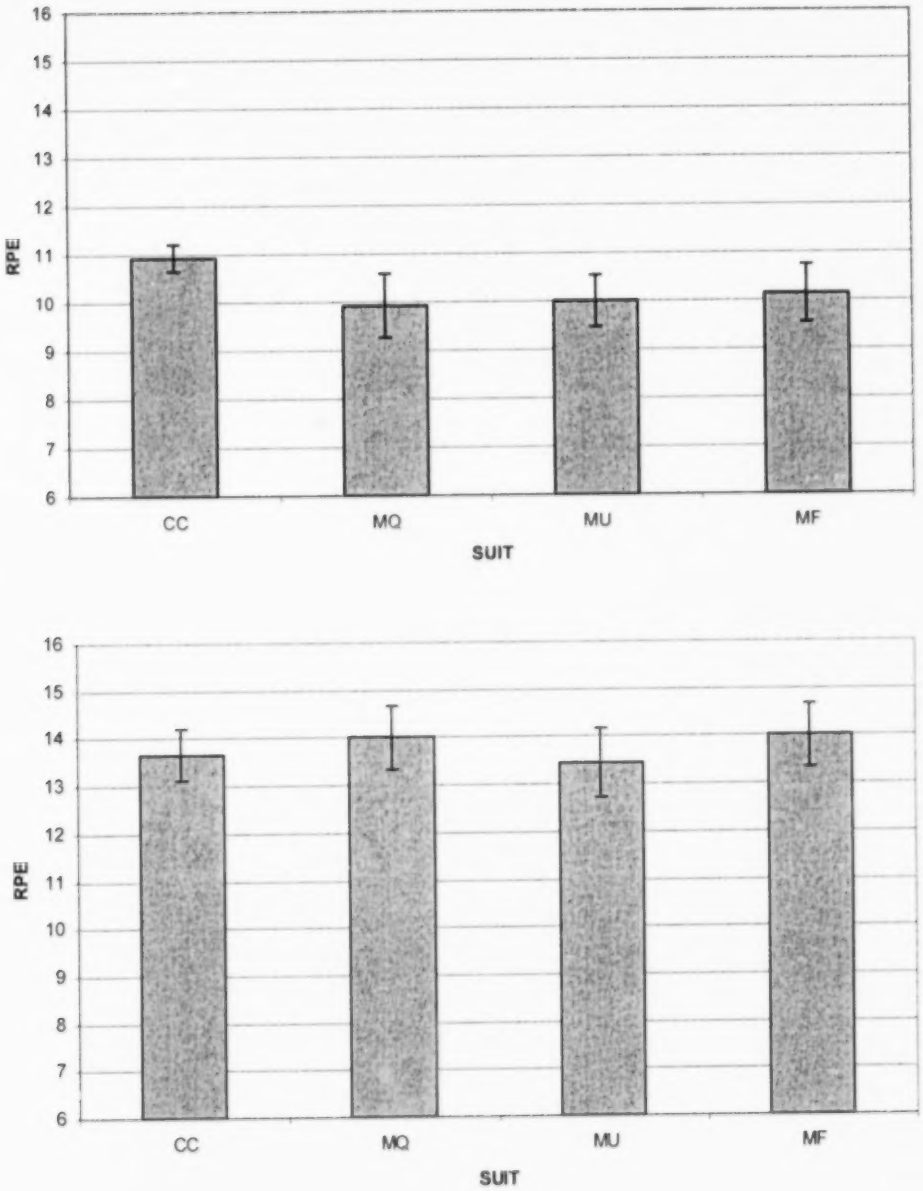


Figure 9. Mean rate of perceived exertion for the 7 subjects for 75-80 min resting phase (top) and 95-100 min exercising phase (bottom). CC: current suit and liner; MU: modified suit with unquilted Thinsulate®; MQ: modified suit with quilted Thinsulate®; MF: modified suit with foam.

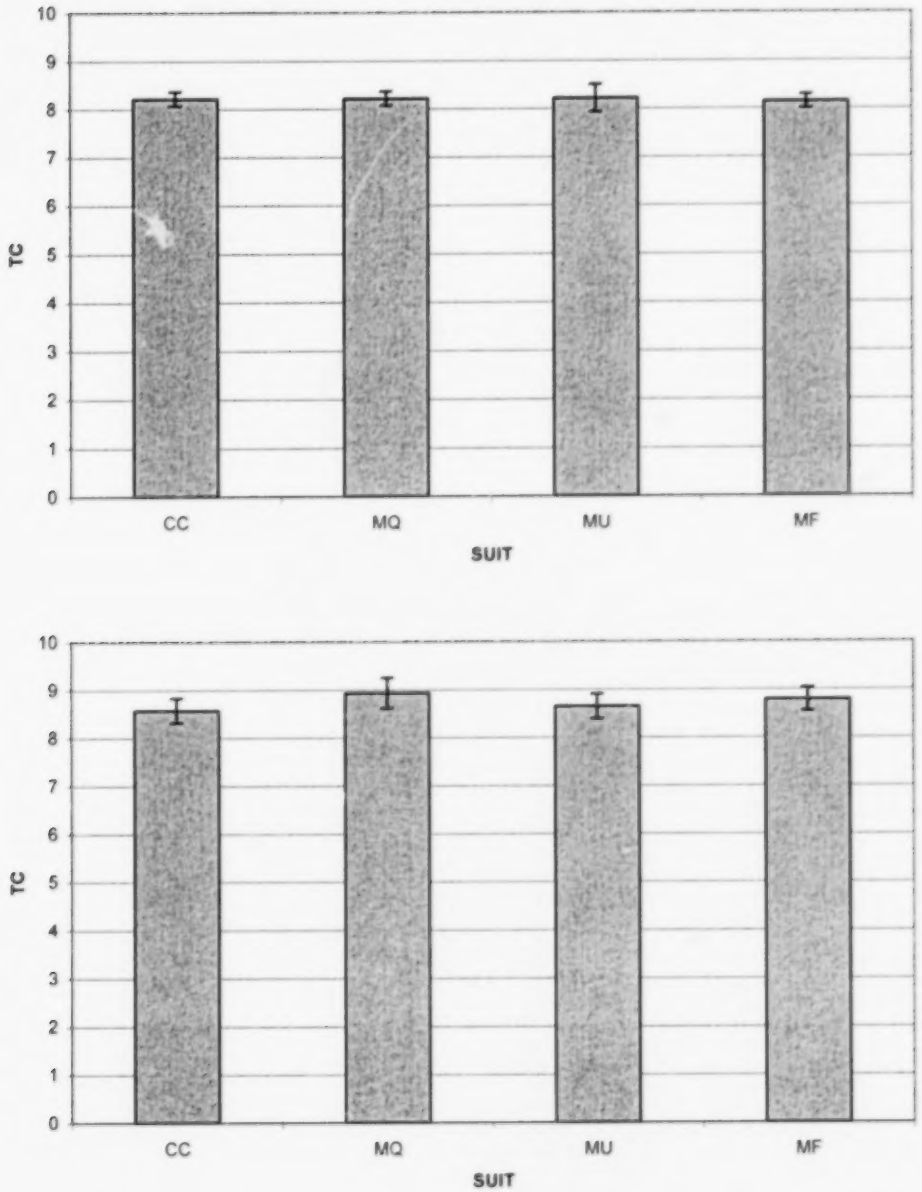


Figure 10. Mean thermal comfort rating for the 7 subjects for 75-80 min resting phase (top) and 95-100 min exercising phase (bottom). CC: current suit and liner; MU: modified suit with unquilted Thinsulate®; MQ: modified suit with quilted Thinsulate®; MF: modified suit with foam.

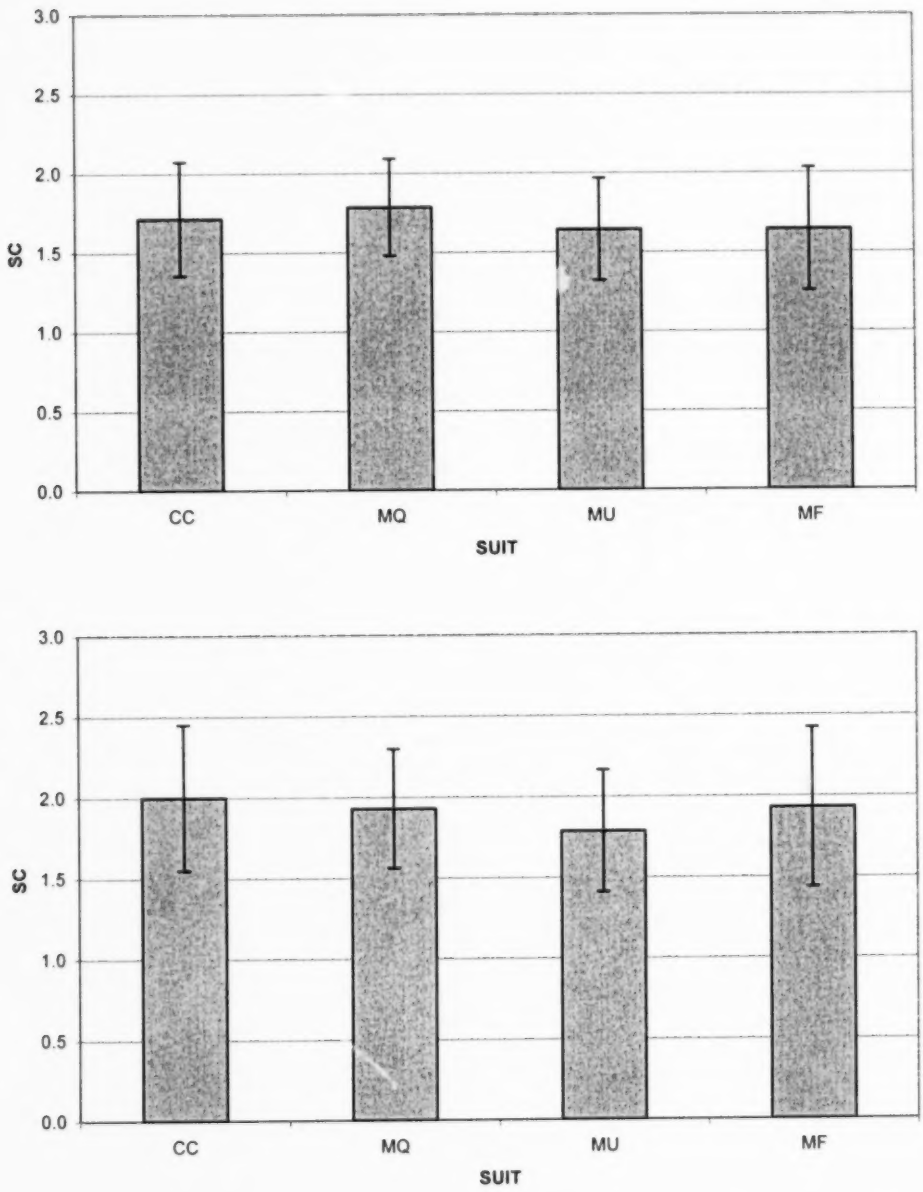
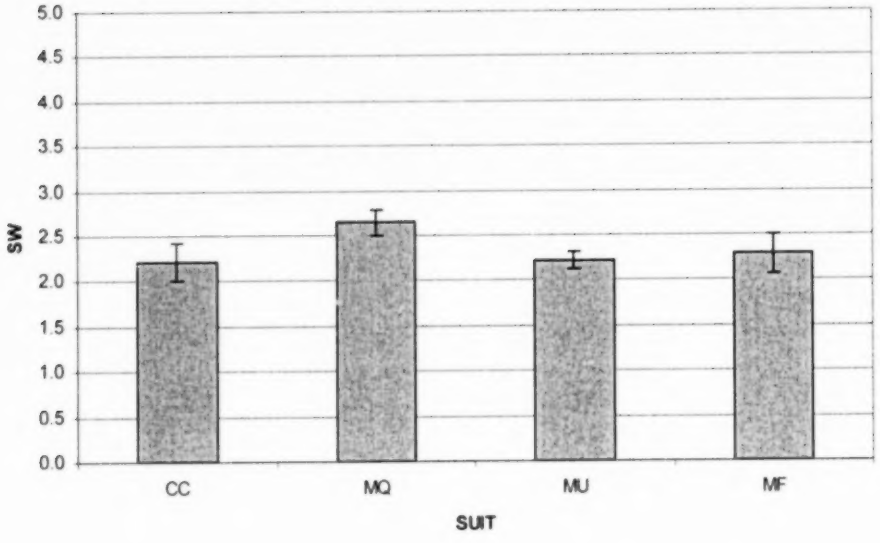


Figure 11. Mean suit comfort rating for the 7 subjects for 75-80 min resting phase (top) and 95-100 min exercising phase (bottom). CC: current suit and liner; MU: modified suit with unquilted Thinsulate®; MQ: modified suit with quilted Thinsulate®; MF: modified suit with foam.



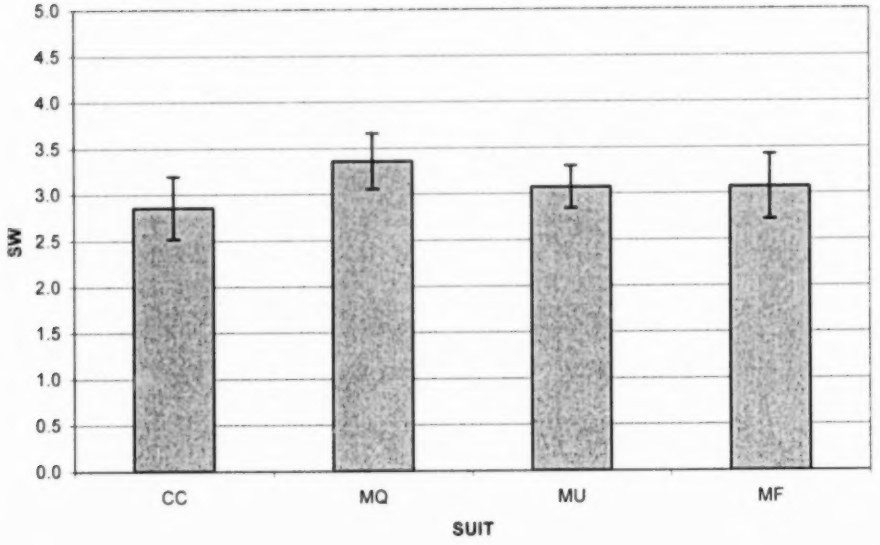


Figure 12. Mean suit wetness rating for the 7 subjects for 75-80 min resting phase (top) and 95-100 min exercising phase (bottom). CC: current suit and liner; MU: modified suit with unquilted Thinsulate®; MQ: modified suit with quilted Thinsulate®; MF: modified suit with foam.

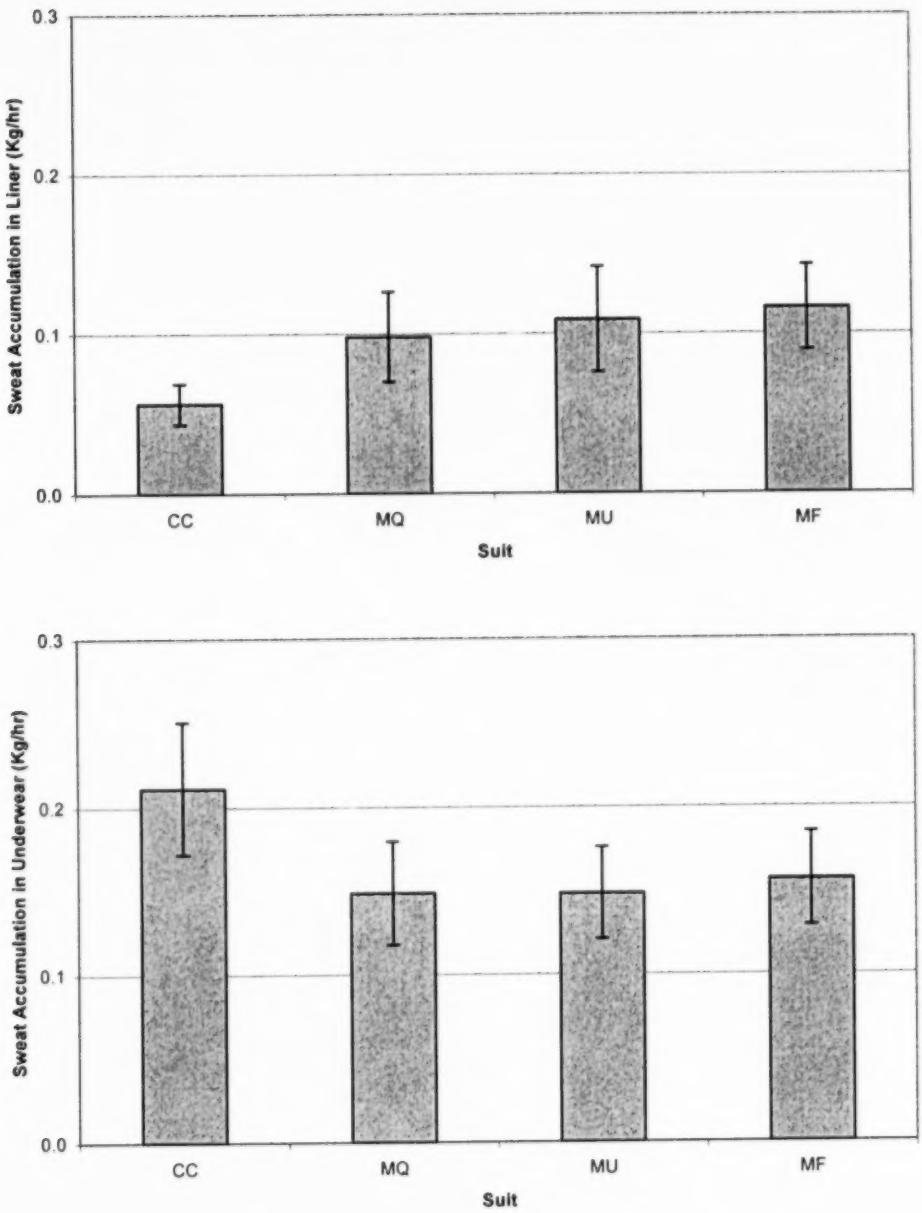


Figure 13. Mean sweat accumulation in liner (top) and underwear (bottom) during the trials for all conditions tested for 7 subjects. CC: current suit and liner; MU: modified suit with unquilted Thinsulate®; MQ: modified suit with quilted Thinsulate®; MF: modified suit with foam.

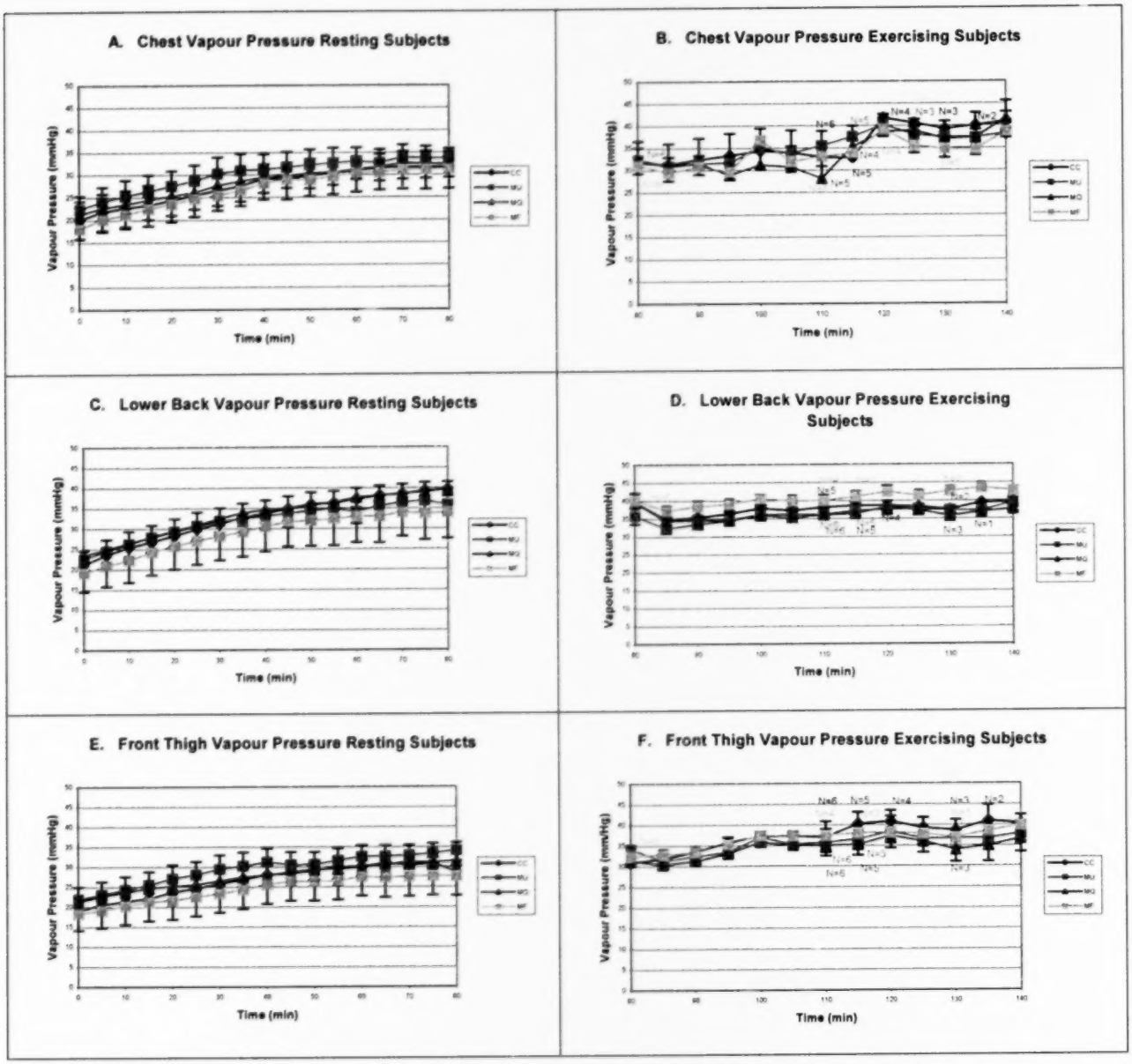


Figure 14. Mean vapour pressure inside the clothing at three locations (chest, lower back, front thigh) during the resting phase (left graphs) and the exercising phase (right graphs) for all conditions tested. CC: current suit and liner; MU: modified suit with unquilted Thinsulate®; MQ: modified suit with quilted Thinsulate®; MF: modified suit with foam.

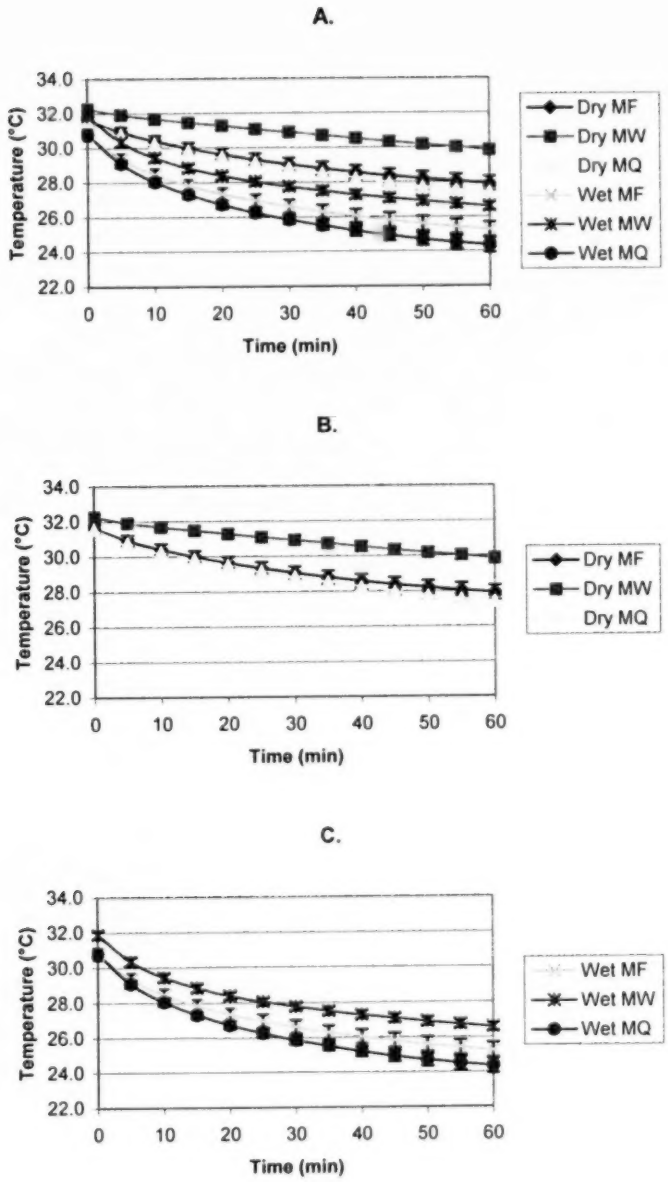


Figure 15. Mean skin temperature during the 60 min. immersion for all conditions tested (graph A). Graph B represents the dry conditions and graph C the wet conditions. N=7 for all conditions tested. MF: modified suit with foam; MW: modified suit with winter liner; MQ: modified suit with quilted Thinsulate®.

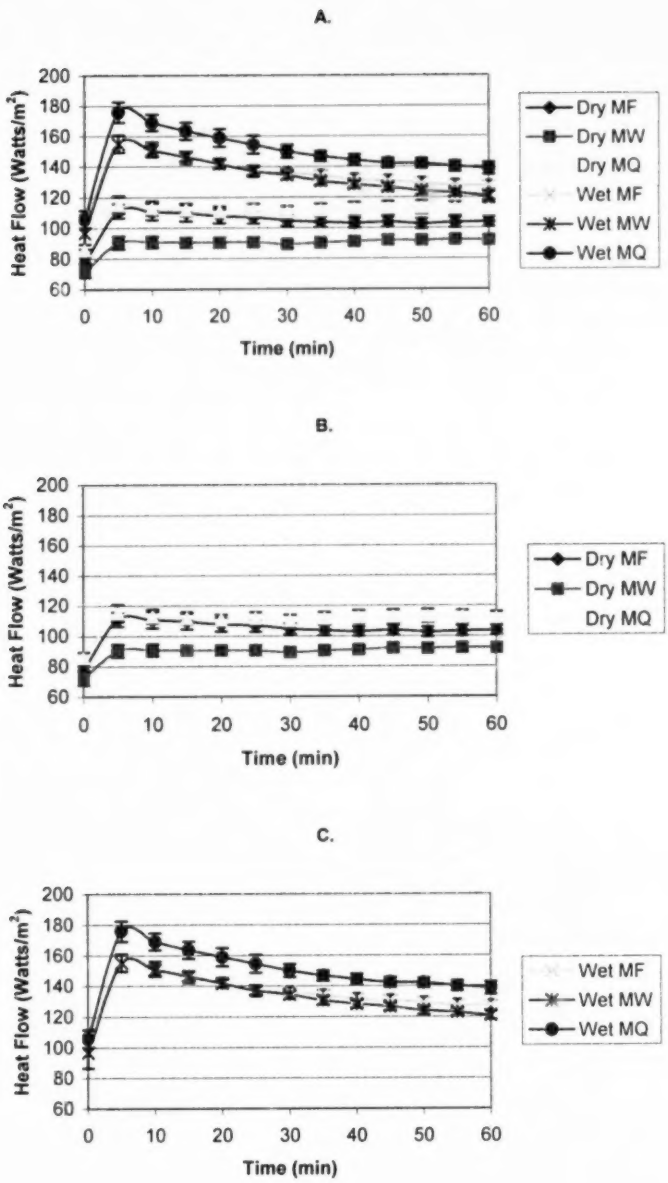


Figure 16. Mean skin heat flow during the 60 min. immersion for all conditions tested (graph A). Graph B represents the dry conditions and graph C the wet conditions. N=7 for all conditions tested. MF: modified suit with foam; MW: modified suit with winter liner; MQ: modified suit with quilted Thinsulate®.

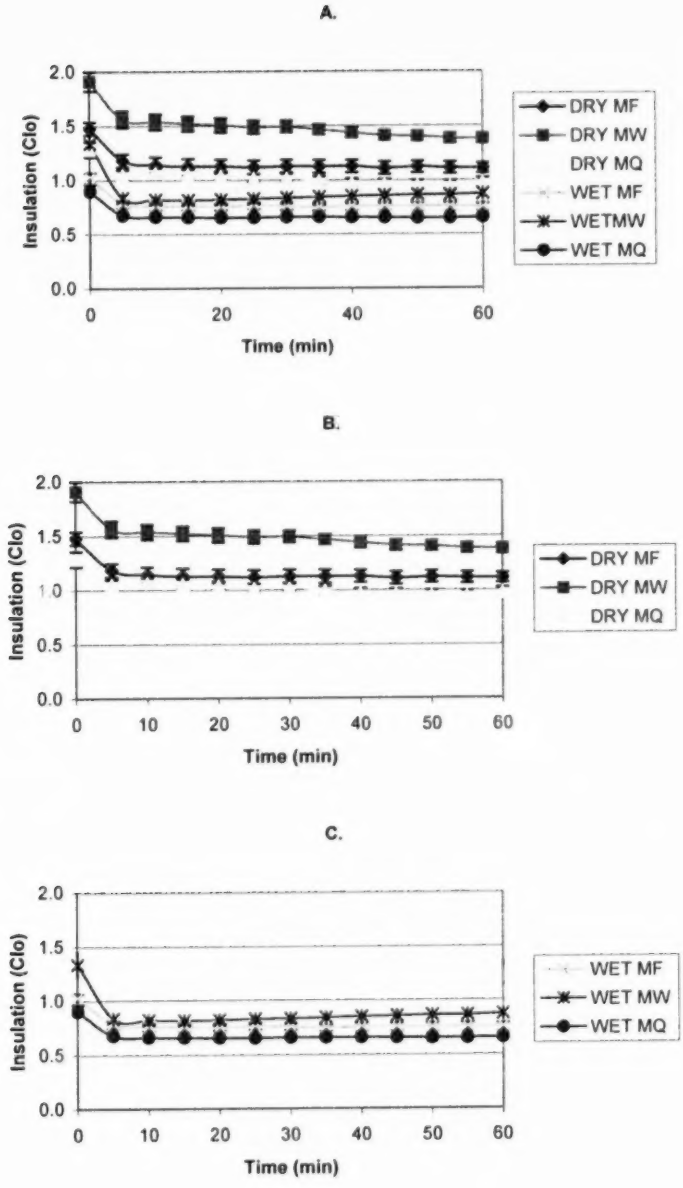


Figure 17. Mean suit insulation during the 60 min. immersion for all conditions tested (graph A). Graph B represents the dry conditions and graph C the wet conditions. N=7 for all conditions tested. MF: modified suit with foam; MW: modified suit with winter liner; MQ: modified suit with quilted Thinsulate®.

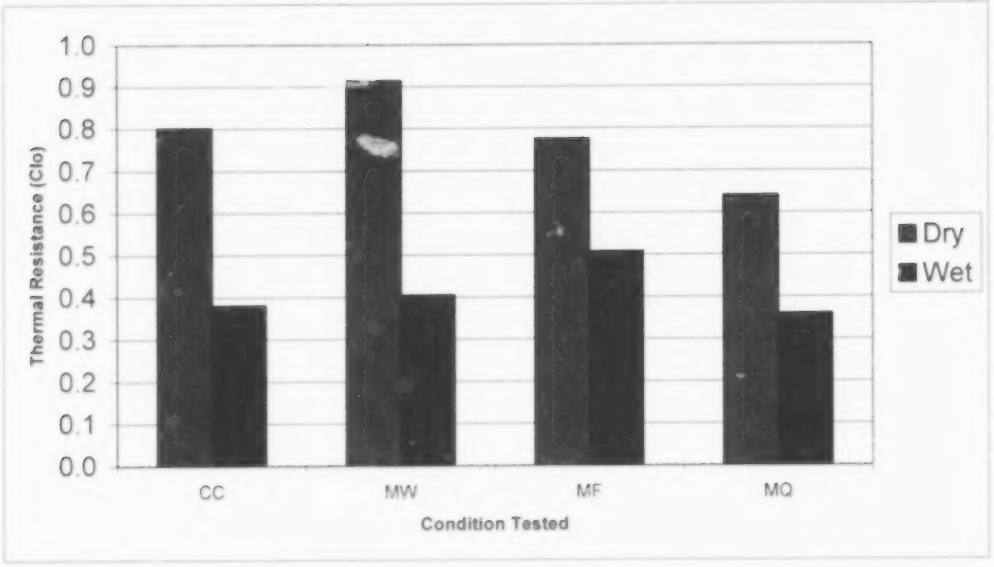


Figure 18. Thermal resistance of the suits as measured by the thermal manikin (TIM from the CORD group). CC: current suit and liner; MW: modified suit with winter liner; MF: modified suit with foam liner; MQ: modified suit with quilted Thinsulate®.

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Annexes

ANNEX 1

Perceived Exertion Scale.

6
7 very very light
8
9 very light
10
11 fairly light
12
13 somewhat hard
14
15 hard
16
17 very hard
18
19 very very hard
20

McGinnis Thermal Comfort Scale

My body feels:

1) So cold I am helpless
2) Numb with cold
3) Very cold
4) Cold
5) Uncomfortably cool
6) Cool but fairly comfortable
7) Comfortable
8) Warm but fairly comfortable
9) Uncomfortably warm
10) Hot
11) Very hot
12) Almost as hot as I can stand
13) So hot I am sick and nauseated

Suit Wetness Scale

How dry is your skin? 0 (very dry) 1 2 3 4 5 (fully wet)

Suit Comfort Scale

How comfortable is the suit? 0 (very comfortable) 1 2 3 4 5 (very uncomfortable)

ANNEX 2

THERMO-MAN®
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TEST SPECIFICATIONS

File Name	R040804D
System Identification	SPRUANCE
Run Identification	Canadian Military
Time of Test	Wed 04-Aug-04 14:44
Garment Identification	Immersion Config.
Exposure Time	4 sec
Exposure Heat Flux	2 cal/(cm²*sec)
Scan Interval	.5 sec
Acquisition Time	60 sec

Garment/Fabric Comments

Fighter Pilot Immersion Configuration
R040804B: 1.82 (Range 1.78-1.88)

Test Remarks/Pre-Test Comments

Temp: 88F Wind: 3mph Hum: 53% Bar: 30.28

Exposure Remarks/Post-Test Comments

1.0 seconds general surface afterflame, lingering at velcro on right cuff

PROTECTION EVALUATION SUMMARY
MANIKIN BURN INJURY PREDICTION

2nd DEGREE BURN	0 %
3rd DEGREE BURN	7 %
TOTAL PREDICTED BURN INJURY. . . .	7 %

For further information, contact:

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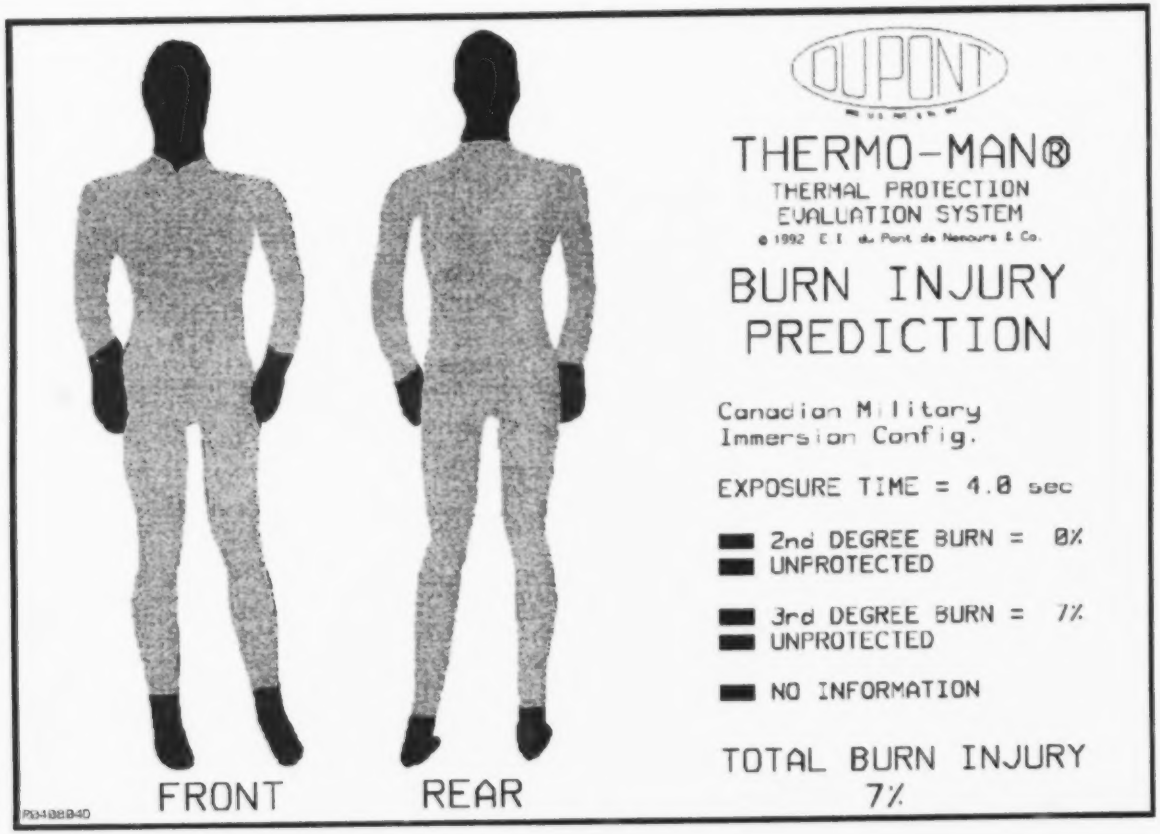
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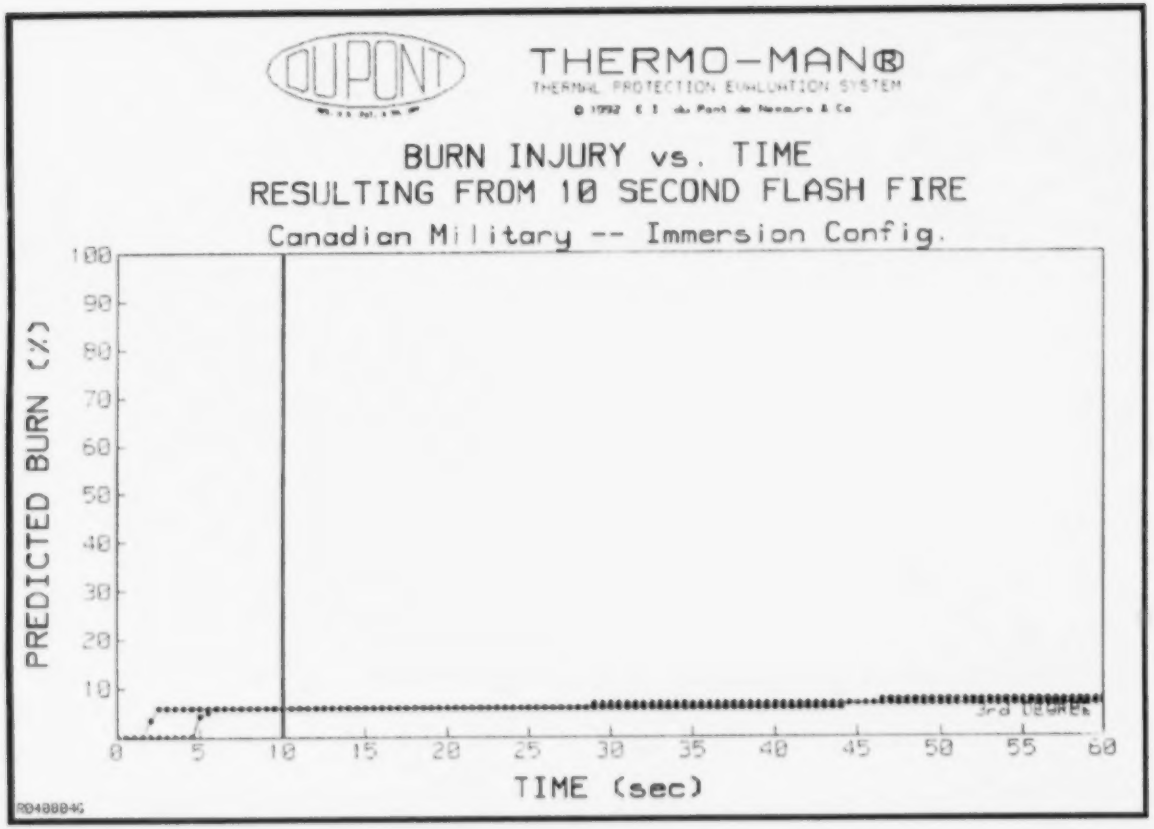
BURN INJURY
PREDICTION
Canadian Military
Immersion Config.
EXPOSURE TIME = 4.0 sec
2nd DEGREE BURN = 0%
UNPROTECTED
3rd DEGREE BURN = 7%
UNPROTECTED
NO INFORMATION
TOTAL BURN INJURY
7%
FRONT
REAR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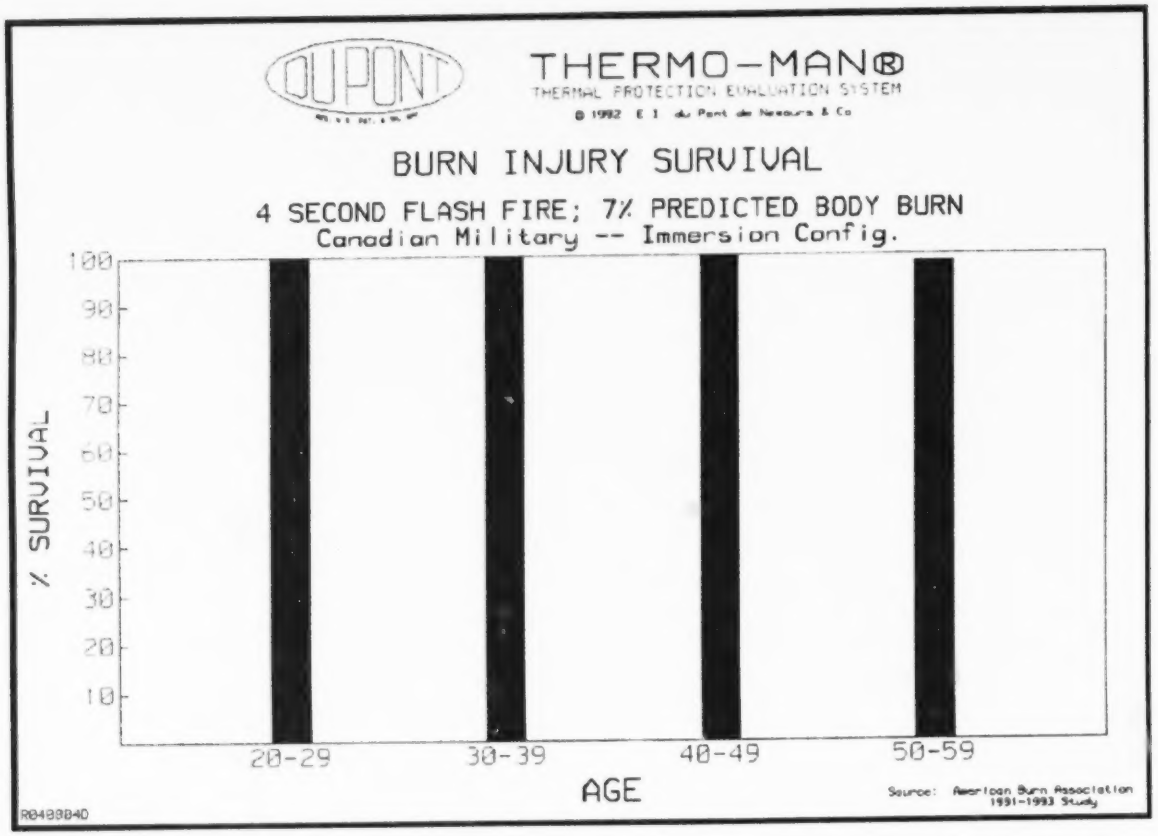
BURN INJURY vs. TIME
RESULTING FROM 10 SECOND FLASH FIRE
Canadian Military -- Immersion Config.
PREDICTED BURN (%)
100
90
80
70
60
50
40
30
20
10
0
5
10
15
20
25
30
35
40
45
50
55
60
TIME (sec)
3rd Degree
RD488846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BURN INJURY SURVIVAL
4 SECOND FLASH FIRE; 7% PREDICTED BODY BURN
Canadian Military -- Immersion Config.
% SURVIVAL
100
90
80
70
60
50
40
30
20
10
20-29
30-39
40-49
50-59
AGE
Source: American Burn Association 1991-1993 Study
R8493B40

ANNEX 3

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TEST SPECIFICATIONS

File Name	R040804G
System Identification	SPRUANCE
Run Identification	Canadian Military
Time of Test	Wed 04-Aug-04 16:19
Garment Identification	Immersion Config.
Exposure Time	10 sec
Exposure Heat Flux	2 cal/(cm²*sec)
Scan Interval	.5 sec
Acquisition Time	60 sec

Garment/Fabric Comments

Fighter Pilot Immersion Configuration
R040804B: 1.82 (Range 1.78-1.88)

Test Remarks/Pre-Test Comments

Temp: 88F Wind: 3mph Hum: 53% Bar: 30.28

Exposure Remarks/Post-Test Comments
---
vigorous afterflame all over garment, lingering at meltable hardware

PROTECTION EVALUATION SUMMARY
MANIKIN BURN INJURY PREDICTION

2nd DEGREE BURN	1 %
3rd DEGREE BURN	7 %
TOTAL PREDICTED BURN INJURY. . . .	8 %

For further information, contact:

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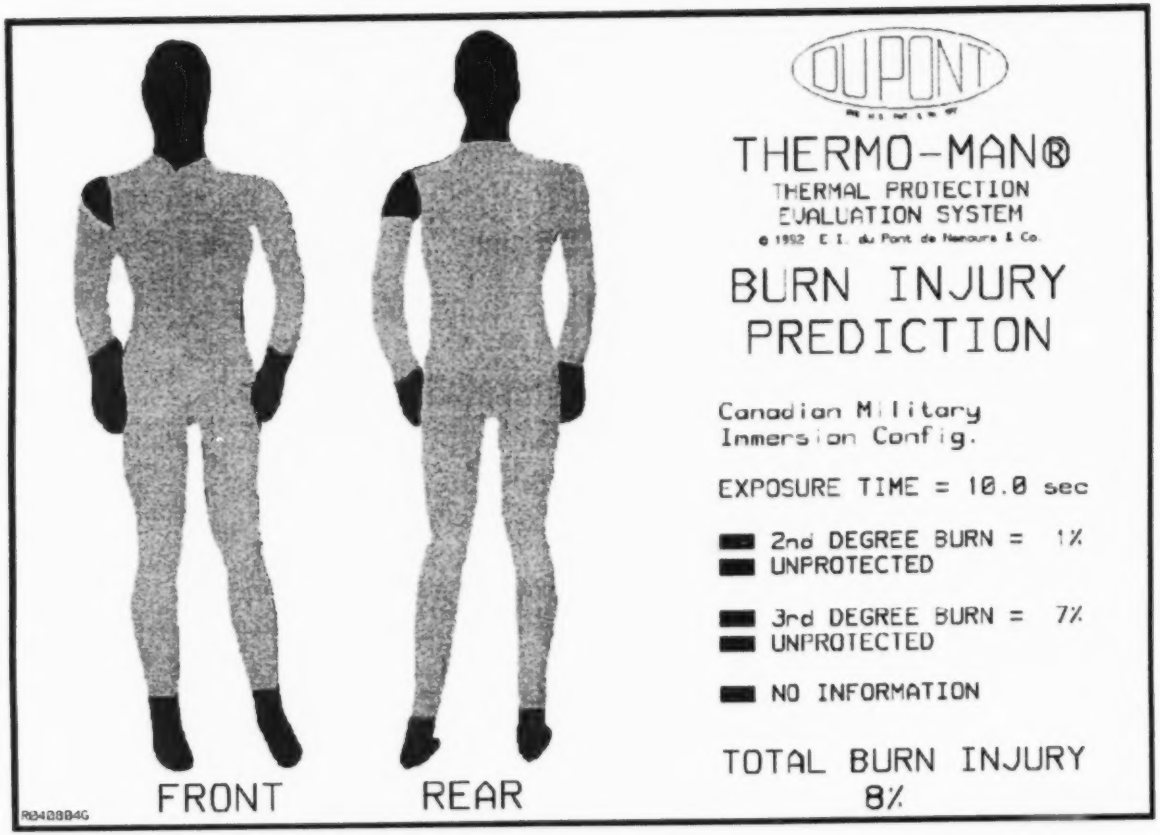
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THERMAL PROTECTION
EVALUATION SYSTEM
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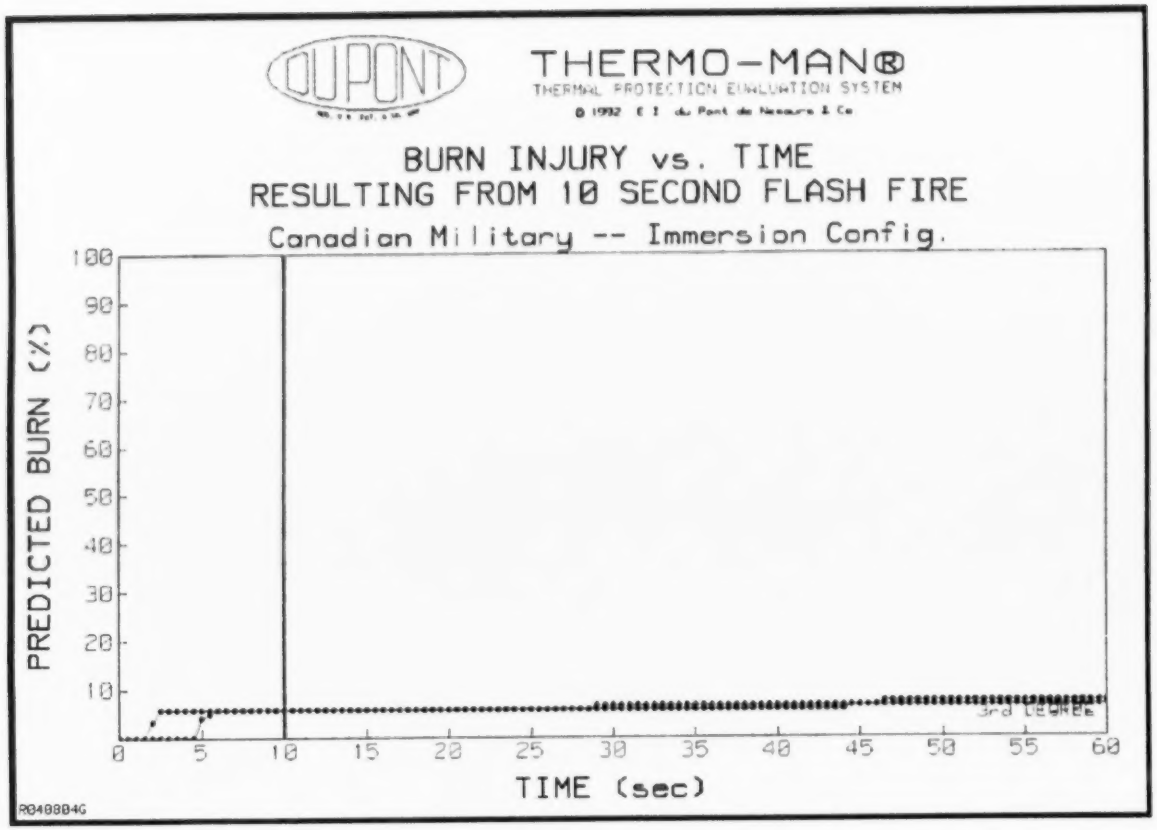
BURN INJURY
PREDICTION
Canadian Military
Immersion Config.
EXPOSURE TIME = 10.0 sec
2nd DEGREE BURN = 1%
UNPROTECTED
3rd DEGREE BURN = 7%
UNPROTECTED
NO INFORMATION
TOTAL BURN INJURY
8%
FRONT
REAR
R0408804G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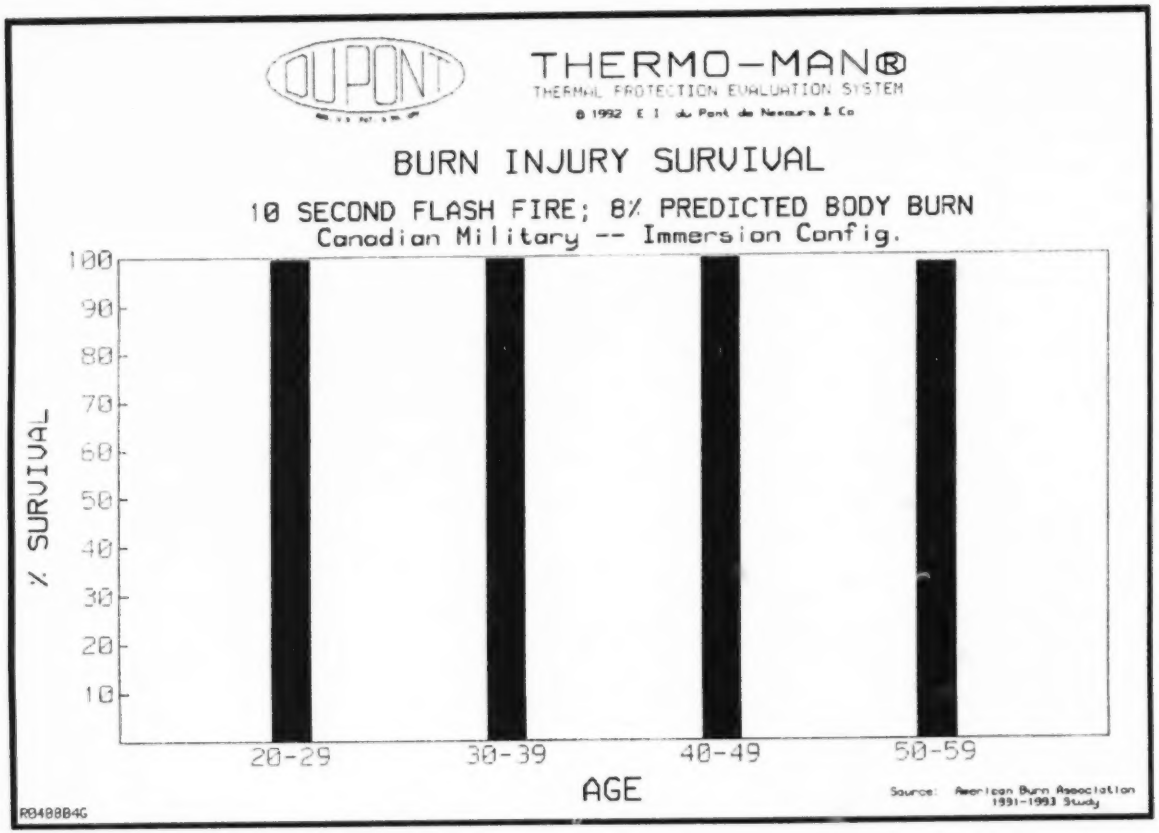
BURN INJURY vs. TIME
RESULTING FROM 10 SECOND FLASH FIRE
Canadian Military -- Immersion Config.
PREDICTED BURN (%)
100
90
80
70
60
50
40
30
20
10
0
5
10
15
20
25
30
35
40
45
50
55
60
TIME (sec)
3rd DEGREE
R0488B4G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BURN INJURY SURVIVAL
10 SECOND FLASH FIRE; 8% PREDICTED BODY BURN
Canadian Military -- Immersion Config.
% SURVIVAL
100
90
80
70
60
50
40
30
20
10
20-29
30-39
40-49
50-59
AGE
Source: American Burn Association 1991-1993 Study
R0488B4G

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4. AUTHORS (First name, middle initial and last name. If military, show rank, e.g. Maj. John E. Doe.)

Michel B. Ducharme

5. DATE OF PUBLICATION (Month and year of publication of document.)	6a NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.)	6b. NO. OF REFS (Total cited in document.)
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(U) Many deficiencies have been identified with the current helicopter aircrew constant wear immersion suit (CWS). In collaboration with the CF Directorate of Technical Airworthiness (DTA) and Mustang Survival Inc., DRDC Toronto proposed a series of short−term solutions to resolve some of the most pressing problems. Those solutions include modified fire resistant neck and wrist seals (open seal design) to replace the rubber seals, and a redesigned liner. The objective of this report is to present the results of the evaluation of those solutions in three environmental situations: an aircraft simulated environment trial (trial #1); a cold water immersion trial (trial #2); and a flash fire trial (trial #3). Trial #1 was conducted in a climatic chamber at DRDC Toronto maintained at 25ºC. During the trial, 7 aircrews from HOTEF were tested during simulated aircrew activities (pilots and backenders) for their physiological heat load, thermal comfort, and sweat transfer into the clothing. Four suit configurations were tested: the current suit and liner (CC); the modified suit (with open neck seal) and Thinsulate® liners (quilted [MQ] and unquilted [MU] liners); and the modified suit and foam liner (MF). The results showed no differences in the heat load between conditions but a better sweat evaporation and transfer for the MU and MQ suits. Trial #2 was conducted in a wave pool at the CORD Group maintained at ~10ºC. During the trial, 7 aircrews from HOTEF were tested during a 1−hour immersion in cold water for their skin temperature and heat loss, and the thermal insulation of the suits. Six suit configurations were tested: the MQ suit dry and wet (2 liters of water introduced into the suit); the MF suit dry and wet; and the MW (modified suit with a winter liner similar to the current liner but 3 times thicker) dry and wet. The results showed that the MW suit had the best dry thermal insulation but the MF suit retained best its thermal insulation when wet. The MQ suit had the worst thermal insulation when dry or wet and showed the largest skin heat loss and the lowest skin temperatures. Similar relative insulation results were obtained from the thermal manikin tests (TIM from the CORD Group). Trial #3 was conducted on the Thermo−man® Thermal Protection Evaluation System from DuPont. The MF suit was tested during a standard 4−sec burn test and showed no evidence of skin burn. It is recommended from those trials to adopt the open seals design to improve comfort and sweat transfer through the protective clothing and to select the foam liner because of the better retention of its thermal insulation during water immersion when wet.

(U) De nombreuses lacunes ont été décelées sur la combinaison flottante de bord (CFB) que doit porter de façon continue l'équipage d'un hélicoptère. En collaboration avec la Direction − Service technique de la navigabilité aérienne (DSTNA) des FC et de l'entreprise Mustang Survival Inc., RDDC Toronto a proposé une série de solutions à court terme pour régler certains des problèmes les plus pressants. Ces solutions englobent une doublure repensée et des joints modifiés de cou et de poignets résistant au feu (concept de joint ouvert) pour remplacer les joints en caoutchouc. Le présent rapport fait état des résultats de l'évaluation de ces solutions dans trois situations différentes : un essai dans un environnement simulé d'aéronef (essai no 1), un essai en condition d'immersion dans l'eau froide (essai no 2) et un essai lors d'un feu à inflammation instantanée (essai no 3). L'essai no 1 a été effectué dans une enceinte climatique de RDDC Toronto maintenue à 25 ºC. Pendant l'essai, qui consistait à simuler des activités effectuées par le pilote et l'équipage, 7 membres de l'IEEOH ont été évalués afin de déterminer la charge thermique physiologique, le confort thermique et le transfert de la sueur aux vêtements. Quatre configurations de combinaisons ont été testées : la combinaison et la doublure actuelles (CC); la combinaison modifiée (avec joint de cou ouvert) et des doublures Thinsulate® (doublures matelassée [MQ] et non matelassée [MU]); et la combinaison modifiée avec doublure en mousse (MF). Les résultats n'ont indiqué aucune différence dans la charge thermique entre les conditions d'essai, mais une meilleure évaporation et un meilleur transfert de la sueur dans le cas des combinaisons MU et MQ. L'essai no 2 a été effectué dans une piscine à vagues de CORD Group maintenue à ~10 ºC. Lors de l'essai qui consistait en une immersion d'une heure dans l'eau froide, 7 membres d'équipage de l'IEEOH ont été évalués afin de vérifier la température cutanée et la perte de chaleur ainsi que l'isolation thermique de la combinaison. Six configurations de combinaisons ont été testées : la combinaison MQ – sèche et humide (2 litres d'eau ayant été versés dans la combinaison); la combinaison MF – sèche et humide et la combinaison MW (combinaison modifiée avec une doublure d'hiver similaire à celle actuellement utilisée mais 3 fois plus épaisse) – sèche et humide. Les résultats ont démontré que la combinaison MW présentait la meilleure isolation thermique à sec, mais que la combinaison MF conservait mieux son isolation thermique lorsque mouillée. La combinaison MQ a affiché les pires résultats – moins bonne isolation thermique, type sec et humide, plus grande perte de chaleur et température cutanée la plus basse. Des résultats semblables pour l'isolation relative ont été obtenus lors des essais réalisés avec le mannequin thermique (TIM de CORD Group). L'essai no 3 a été mené avec Thermo−man® − le système d'évaluation de la protection contre la chaleur de DuPont. La combinaison MF a été testée lors d'un essai standard d'exposition à un feu de 4 s qui n'a révélé aucune brûlure au corps. À la lumière de ces essais, il est recommandé d'adopter le concept de joint ouvert pour améliorer le confort et le transfert de la sueur aux vêtements de protection et de choisir la doublure en mousse qui offre une meilleure rétention de l'isolation thermique lors de l'immersion dans l'eau lorsqu'elle est mouillée.

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(U) hypothermia, thermal comfort, survival time, flame resistance, heat stress